

# **The Journal of Mathematics and Science:**

COLLABORATIVE EXPLORATIONS

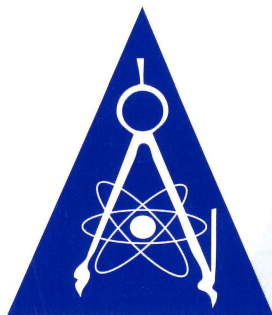
Volume 3, Number 1    Spring 2000

## **PART I: SPECIAL ISSUE**

### **The New York Collaborative for Excellence in Teacher Preparation (NYCETP)**

Focusing on the Power of Collaboration

## **PART II: REGULAR JOURNAL FEATURES**



Virginia Mathematics and Science Coalition

# The Journal of Mathematics and Science:

COLLABORATIVE EXPLORATIONS

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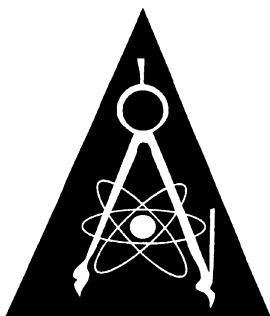
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# **The Journal of Mathematics and Science:**

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## **SPECIAL ISSUE**

**The New York Collaborative for Excellence  
in Teacher Preparation**

**Coordinating Editor  
for this Special Issue**

Barbara C. Freeouf  
NYCETP City-Wide Coordinator



## *Coordinating Editor's Note*

The New York Collaborative for Excellence in Teacher Preparation (NYCETP) is a 5-year project funded by the National Science Foundation (DUE #9453606). It is a partnership of five colleges of the City University of New York (Brooklyn, City, Hunter, Lehman, and Staten Island) and New York University. The central purpose of our Collaborative is to improve the preparation of elementary and secondary teachers of science and mathematics. To this end, we have been engaged in six interrelated clusters of activities, including:

- developing new approaches to teaching and assessing science and mathematics in college courses;
- providing new training opportunities including the design of new courses for prospective teachers at all levels;
- developing new training materials, with special emphasis on the design of curriculum units which reflect collaboration among faculty of varied disciplines and K-12 teachers, and reflect our urban context;
- providing student support and career development, including follow-up of first year teachers and internships in settings such as college tutoring, K-12 classrooms, and local science museums;
- recruiting promising students into teaching;
- developing exemplary field sites for student teachers.

NYCETP provides a model for how teacher preparation programs can support school change. Lasting effects of our Collaborative have resulted from the formation of a cohort of university faculty from many disciplines with a commitment to teacher preparation, and the creation of new links between college faculty and K-12 teachers, as well as links between science-rich institutions and educators at all levels. Of particular importance to the success of NYCETP has been the collaboration and cooperation between education and liberal arts faculty, and among the various science and mathematics faculties.

The NYCETP Vision and Philosophy of Mathematics and Science Teacher Preparation has guided the development and implementation of all Collaborative activities. In this publication more than a dozen project participants provide insights into selected activities. This selection of our collective work demonstrates the ways in which NYCETP participants are using strategies advocated by reformers, including inquiry-based learning, cooperative learning, alternative assessments, to achieve the project's goal to change the quality of science and mathematics teaching and learning in our schools. The chart below offers a summary of the articles in this special issue:

<i>Author</i>	<i>Pg. #</i>	<i>Inquiry-Based Learning</i>	<i>Coop. Learning</i>	<i>Alternative Assessment</i>	<i>Urban Context</i>	<i>Constructivism</i>	<i>Std. Based Curricula</i>	<i>Intg. of Tech.</i>
Lazarus	1	X	X	X		X		X
Adler	9		X					
Sobel	15	X						
Fraser-Abder	29	X	X		X	X		
Espinoza	35	X		X	X		X	X
Miele	41	X	X		X	X	X	X
Murfin on projects	47	X	X			X	X	X
Stone	55	X	X	X				X
Ring	65		X	X	X		X	
Welchman	75			X			X	
Goldberg	83	X	X	X	X	X		X
Murfin (sci. fair)	91			X	X	X	X	X
Jordan	99	On teaching scholars and recruitment						
Tittle et al	107	On using case studies for changing curricula						

By focusing on the “Power of Collaborations,” our intention in this issue was to seed more professional interactions among colleagues and to inspire others to also take up our cause to continually seek excellence in teaching mathematics and science at all levels. At the same time, however, we recognize that collaborative work is never easy. As with all worth-while endeavors, collaborations are fraught with challenges. In the end, their power lies in the processes shared, the products produced, and the connections made on many levels - - personal, professional, curricular, and institutional.

NYCETP is pleased to present a sampling of such processes, products and connections. Our hope is that the work described here will invite professional discourse beyond our own institutions, as we collectively continue to find better and better ways to prepare excellent teachers and become excellent teachers ourselves. We are grateful to the editorial board of the Journal for their willingness to devote a special issue to the work of the NYCETP project. Professors Raychowdhury and Haver, Karen Murphy and other excellent staffers made the entire process particularly smooth and simple.

Finally, other publications that chronicle the development of NYCETP courses and related activities will be available for dissemination during the 2000-2001. If the reader is interested in receiving detailed information about any of the activities mentioned here or elsewhere, we invite you to contact the Collaborative office, the campus coordinators, or the authors in this publication.

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# **A GENERAL CHEMISTRY COURSE FOR PROSPECTIVE ELEMENTARY SCHOOL TEACHERS**

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The paper describes a general chemistry course designed for students who are planning to become elementary school teachers. The course has been structured so as to transmit the fun and excitement of experiencing chemistry and uncovering its basic principles by centering on laboratory and other discovery experiences. In addition, the course uses peer led workshops in which the students discuss these experiences. The course is thus a product of a particularly strong collaboration between public schools and college faculties. It is going to become a part of a new four-course sequence that will be required of all students intending to earn elementary education certification at Lehman College.

## **Introduction**

This course is a one-semester, general chemistry course that has been redesigned specifically for students who intend to become elementary school teachers. It is a course, however, that should be appropriate for any non-science major. It has been transformed from a lecture course that surveys all of chemistry together with a laboratory that only, at best, validates the ideas discussed in the lecture; to a course that can transmit the fun and excitement of experiencing chemistry and uncovering its basic principles. In earlier work done by others, general chemistry courses for science majors have been developed that use either inquiry based methods [1] or collaborative learning approaches [2]. This paper describes a course that uses both. In this dynamic approach, the students are exposed to many chemical experiences, and learn how the concepts of chemistry explain what is observed. In addition, there are demonstrations as well as lectures for those aspects of the course that cannot be covered in the laboratory. After each experiment, the students participate in peer led workshops in which they get into discussions with one another about the experiments that have been done, and their meaning.

The idea for this course came out of discussions held between Marc Lazarus and Katina Lotakis, a middle school assistant principal in September of 1994. At that time, they were both working in the Transitional Grades Science Leadership Institute Project (TGSLIP), a program to improve the science backgrounds of fifth and sixth grade teachers funded by an Eisenhower Grant. Since undergraduates fear chemistry and many

had failed, it was hoped that approaching the course with hands-on activities that were not just for verification of chemical laws or theories would lead to a better understanding of the content and concepts taught. When the New York Collaborative for Excellence in Teacher Education (NYCETP) began, Mrs. Lotakis together with Debra Hendry, a middle school science teacher, and Ellen Funk, an elementary school teacher, formed an advisory committee that reviewed the laboratory experiments, workshop questions, and lecture notes; and, they provided input as to where misconceptions would arise for the learner. The course is thus a product of a particularly strong collaboration between public schools and college faculties.

### **Details of the Course**

There is no formal textbook for the course. In essence, the notes that summarize the student's experiences become the textbook for the course. The idea behind this approach is that a student can better understand ideas when they have experiences to relate to them. Thus, experiences here precede explanations.

The course is set up so that there is a 2-hour lecture on one day, followed by a three-hour laboratory on another day. A typical class will have about 20 students in it. On the first day of class, we break the class up into four workshop groups. There are two workshop leaders who are chemistry majors and who are typically in their second or third year of chemistry courses. Each of these workshop leaders runs two of the workshop groups. On the first day of class, the evaluation exam is given; of the 19 questions on this test, most students get 2 right. A couple of students will get 8 or 9 right, while a couple of students will get none right.

The first meeting in the laboratory takes place on the second day of class. The students form lab partnerships. These are usually made up of two or three students who work together. The students are told to carefully write down what they observe. They are also told that each student will have to write a laboratory report for each experiment performed during the semester. The report is to contain: an experimental section describing what they did, together with any materials that were used; a section on results which includes a discussion that carefully describes all the observations made, and any appropriate interpretations of these observations; and, a conclusion section summarizing any general ideas that can be extracted from the experiment. Before the report can be



written, the students will have attended the next class session. In each lecture class following the laboratory, there are workshop discussions designed to get students to participate in answering the assigned workshop questions. A lecture is then given which emphasizes the main points that come out of the workshop, and includes some additional insights. When all of the workshop questions have been discussed and all of the lecture material has been covered, then and only then are the students given a set of notes summarizing the main ideas obtained from the laboratory, the workshops, and the lectures.

It is apparent that the course is based on an inquiry-based model that uses collaborative methods as well.

The following paragraphs provide a listing of the basic topics covered as well as the types of experiences used to cover the topics.

1. **Chemical Reactions:** In this first laboratory, the students observe a series of chemical reactions. They learn about making careful observations and the language used to describe the observations; and, that color changes, formation of a precipitate, bubbling of gases, and the giving off of heat are often indicative of a chemical reaction.
2. **Tests for Some Common Substances:** In this experiment, various gases are prepared and tests for each gas developed. The gases that are prepared are Hydrogen, Oxygen, and Carbon Dioxide. In addition, a test for water is developed.
3. **Mass, Weight, and Volume:** The questions what is mass, what is volume, and how are they different from one another are examined, as well as the law of conservation of mass for chemical reactions. By seeing a demonstration of weighing performed on both a spring scale, and a two-pan balance, students are able to observe the difference between mass and weight. By measuring volumes, students are able to see that it is the space occupied. Different groups of students run different precipitation reactions, and they observe for themselves that the law of conservation of mass is obeyed. They also run a reaction in which one of the products is a gas, and they should be able to explain why there appears to be a loss of mass.
4. **Combustion:** Change in mass of a candle before and after burning as well as the

change in mass of a metal before and after heating in air, is examined. This produces the question: why does the candle lose weight while the metal gains weight? The results are analyzed in terms of the law of conservation of mass. The composition of air, together with an explanation for combustion, is achieved by doing an experiment that shows only 20% of the air combines with a metal and that the remaining gas does not give positive tests for hydrogen, oxygen, or carbon dioxide. In addition, experiments are done that show that a burning candle requires air, and that it produces carbon dioxide and water. Other experiments also show that if the amount of air is limited, the metal gains less mass than when completely exposed to air.

5. **Mixtures, Pure Substances (Elements and Compounds):** By examining mixtures and pure substances, it is concluded that the components of a mixture retain their identities. It can be concluded from previous experiments that a metal that combines with oxygen in the air is unlikely to decompose, and belongs to a class of pure substances called elements, while certain other pure substances can be decomposed and are called compounds. Students conclude that although a compound is composed of two or more elements, it is not a mixture and has a unique identity different from the elements of which it is composed.
6. **Atoms:** From examining an ordinary substance and thinking about it, together with the existence of elements, compounds, and chemical reactions, the student is able to see how the existence of atoms can be inferred. It can also be shown how the law of conservation of mass is explained by the atomic concept. An experiment is done to demonstrate the law of definite proportions. By making magnesium oxide, this law can be demonstrated. The idea that atoms of fixed mass characterize an element can be inferred from this law.
7. **Periodic Table:** The students design their own Periodic Table of the Elements for just 10 elements. They see if they can make predictions by looking at the current table. They learn the symbols of the common elements.
8. **Chemistry and Electricity:** The students do experiments to show that an electric current can be obtained from a chemical reaction. A demonstration of the electrolysis of water done in experiment 6, as part of topic 5, shows that electricity can be used to produce a chemical reaction. This shows the link between chemistry and electricity. Experiments with static electricity establish the existence of two opposite electric charges, called positive and negative. A

demonstration is done of a cathode ray tube, and experiments with magnets establish that cathode rays are negatively charged. Part of a Power Point presentation on the origins of atomic structure contains animations of the effects of magnetic and electric fields on cathode rays. The presentation includes J.J. Thomson's interpretation of these experiments in terms of a negatively charged electron. We also discuss what constitutes an electric current.

9. **Origin of Atomic Structure:** The experiments that led to the Thomson model of the atom and Rutherford's discovery of the nucleus are shown on additional animations included in the Power Point presentation. Each student is able to see continuous spectra from a white light, as well as line spectra of individual elements using light dispersing gratings. The question arises: why do individual elements produce characteristic line spectra? The Power Point presentation concludes with an animation showing line spectra and how Bohr's model of the atom explains line spectra.
10. **Ions:** Conductivity of various solutions, and melts are examined using a light bulb circuit. Why do certain solutions conduct electric currents while others do not? The concept of the ion explains the observations. The students learn the names and charges of the various common ions, and how to name ionic compounds. Examining various solutions, the colors of a number of ions are identified. The students then experiment with and see for themselves: a) precipitation reactions and, b) single displacement redox reactions. The reactions are explained in terms of what happens to the ions in solution. They also learn how to represent these reactions as chemical equations.
11. **Acids, Bases, and pH:** Certain experiments are done using reactions between metals and acids that suggest that all acids contain the Hydrogen ion. An electrolysis of sulfuric acid solution producing hydrogen at the cathode will show that the hydrogen ion is positively charged. Tests are developed for detecting acids and bases using litmus paper. There is a discussion of the pH scale. They also do experiments from which they can conclude that metal oxides react with water to produce bases, while non-metal oxides react with water to produce acids. The applications to the acid rain phenomenon are discussed.
12. **Chemical Bonding:** By examining the known formulas of various compounds, it is possible to figure out the rules of valence for atoms of each element and how

they relate to the Bohr model of the atom. These rules of valence place limits on the kinds of compounds that can be made, as in organic chemistry.

The course is structured so as to expose various components of the scientific strategy. The opening part of the course (Topics 1 and 2 in the syllabus) is designed to develop an appreciation of careful observation, and the proper language for recording these observations. At the same time, tests are developed that will help the student understand combustion and other topics in the syllabus further along in the course. Combustion (Topic 4) is studied because it is a subject strongly tied to the origins of modern chemistry, and is an important common phenomenon that too few students seem to understand. It also can be interpreted in terms of the law of conservation of mass, which is discussed as part of Topic 3. This demonstrates how laws arise out of generalizations of observations. This again is seen in Topic 6 for the law of definite proportions. Topic 6 also shows, using atomic theory as an example, how theories arise to explain laws and observations. Topic 7 uses the development of the periodic table to show the importance of classification in science. The use of symbols for elements and compounds (Topics 5, 6, 7, 10) and the use of chemical equations (Topics 10 and 11) show the importance of representation in science. The evolution of the atomic model (Topics 8 and 9) demonstrates how scientific theories are changed as new experimental observations are made. Chemical Bonding (Topic 12) demonstrates how scientists search for the limits that nature imposes. Not every conceivable compound can be made.

Although the topics covered in this course are very basic and fundamental, discussions with science majors have led the author to conclude that many of these majors are not well grounded; they have difficulty understanding some topics, such as combustion. In addition, workshop leaders who are chemistry majors and who were taking the senior level inorganic chemistry course have commented on how helpful the Power Point presentation on atomic structure was in enabling them to better understand this topic as it was covered in their course.

In order to illustrate further the approach used in the course, the following description of a typical class is included.

### **Description of a Typical Class**

In this experiment, the students prepare three gases. They are, however, not told

what the three gases are. The students are required to make a line drawing of the gas-generating apparatus, together with their descriptions of the starting materials. They are also expected to describe what they see happening in the reaction vessel from which the gases are generated for each of the reactions.

As described in the experiment, they then perform separate tests on three separate samples of each gas. After the students have held a workshop discussion of the experiment, we hold a question and answer session in class in order to make sense out of what the students have observed.

The results of the tests performed on the gases are as follows:

<u>Test</u>	<u>Gas1</u>	<u>Gas2</u>	<u>Gas3</u>
Burning splint	Burned more brightly	Popped	Went out
Glowing splint	Reignited	Nothing happened	Went out
Barium hydroxide	Nothing happened	Nothing happened	White precipitate

It was noted that all three gases were colorless and odorless. However, they had different properties. It can be seen that a gas is defined by its properties. It is then assumed that the students were the first people to make these gases and we have some fun assigning names to the gases. This emphasizes that a name can be assigned to a gas with specific properties. Eventually, the student is told that gas 1 is oxygen, gas 2 is hydrogen, and gas 3 is carbon dioxide. These gases are then seen not just as names, since the student has had some experience with them.

In addition to the experiments on gases, the students test water and another clear, colorless liquid with cobalt chloride paper. The cobalt chloride paper turns from blue to pink in the presence of water, but remains blue in the presence of the other clear, colorless liquid. From this, they learn that not each clear, colorless liquid is water.

The tests for gases as well as the test for water are later used in the study of combustion.



## Conclusion

This course will be a part of the four-course science sequence that will soon be required of all elementary education minors at Lehman College. It is hoped that this course will represent not only the subject of chemistry, but also a better way of teaching it.

The author wishes to thank the New York Collaborative for Excellence in Teacher Preparation funded by the National Science Foundation for the major support of this work. He also wishes to thank the Chemistry Workshop Project, also funded by NSF for additional support. ■

## Bio

Marc S. Lazarus is Chair and Professor in the Department of Chemistry at Lehman College. Since 1995, he has been one of the campus co-coordinators for the NYCETP at Lehman, where he has helped to oversee all the NYCETP activities. Prior to working with NYCETP, he participated in a number of grant funded projects; amongst them was the Transitional Grade Science Leadership Institute Project funded by an Eisenhower grant, and the Chemistry Workshop Project funded by NSF. In addition to working on projects involving educational improvement, Dr. Lazarus has done research in the area of physical inorganic chemistry. He received his Ph.D. in chemistry from Princeton University in 1974.

## References

- [1] R.W. Ricci and M.A. Ditzler, "Discovery chemistry: A laboratory-centered approach to teaching general chemistry," *Journal of Chemical Education*, **68** (1991) 228.
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# **MATHEMATICS WITHOUT LECTURES: SMALL-GROUP LEARNING AT NEW YORK UNIVERSITY**

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This article describes an effort to introduce small-group learning into the mathematics curriculum for the non-specialist at New York University. Starting in spring 1999, students were offered the choice of fulfilling their mathematics requirement in a small-group environment that included no formal lectures. The goal of these groups is to make the transition from relatively inactive, even passive, lectures to an experience that actively engages students in the process of doing mathematics. Contact time was restricted to two weekly classes run by a graduate student and was limited to enrollments of 15-16 students. The course is a small-group version of one that has been offered regularly since 1995, with a format that includes two traditional large lectures and one 100-minute workshop each week. Students in the College of Arts and Science and in the School of Education took the course, and the latter group included future K-12 teachers. Instructors for the small-group sections come from the graduate level Mathematics Education Group in the School of Education and the Mathematics Department in the Graduate School of Arts and Science.

## **Introduction**

Motivating students who take mathematics as a liberal arts requirement for their baccalaureate degree is one of the most difficult problems facing mathematics educators. What should be the content? What pedagogical approach should be used? The trend in mathematics and science education is toward inquiry-based learning in which students are told as little as possible of what is now accepted scientific and mathematical fact. Instead, they are given the opportunity to discover scientific truths by observation, collect data, and draw conclusions by themselves [1,2,3] as a prelude to an introduction to the theory. One can add a laboratory experience to existing lecture-based courses, though this still can leave students with a passive experience in the lecture hall. Some educators now employ techniques for introducing small-group activity into the lecture experience, even if confronted with a large class of students [4].

Another approach is to eliminate the lecture, which frequently has a large enrollment, and to increase the laboratory experience. Mathematics courses without lectures began to be offered at Dickinson College in 1991, through an option, which they call *Workshop Mathematics* [5]. This format of teaching students mathematics in small groups was introduced into the NYU math/science core program (the Morse Academic Plan) in the Spring 1999 semester, repeated in fall 1999 and is being done again in spring 2000. Educational research supporting this method of pedagogy has been appearing in the literature for a number of years [6]. Further motivation was provided in part by attendance in Quantitative Reasoning (the name given to the math part of the NYU core) lectures that are typically 75% of the enrolled students, but sometimes as low as 60%.

Poor lecture attendance and poor course evaluations by students prompted a discussion among the faculty on the Steering Committee that overlooks the math/science core. Members of this committee not only include faculty from the Mathematics Department, but also Kenneth Goldberg of the School of Education and Neville Kallenbach of the Department of Chemistry, both of whom have important roles in the New York Collaborative for Excellence in Teacher Preparation (NYCETP). Their work in the Collaborative informed their ideas about effective instruction, and a fresh perspective on mathematics education for the non-major was introduced into the discussions about Quantitative Reasoning.

Educational research points to something those engaged in college writing programs have known for some time: you learn writing not by listening to a lecture on writing, but by writing. This is how writing is taught at NYU. The small-group effort is based on the philosophy that one learns mathematics by doing mathematics and not by listening to lectures about it. This article documents an effort to introduce this mode of learning into the mathematics core curriculum at NYU.

### **Mathematics Education for the Non-Major at NYU**

The math component of the NYU core curriculum in mathematics for the non-mathematics and non-science major consists of completion of a single course. The component, called Quantitative Reasoning (QR) is not a single course, but is currently a group of 3 courses, any one of which can be taken to fulfill the mathematics requirement. In the standard "lecture format," each course consists of two 75-minute lectures, given by

a faculty member, and one 100-minute workshop, conducted by a graduate student, per week; total weekly contact time is 250 minutes. Lectures typically have enrollments of 126 students and the workshops have 21 students per section. One course, called *Mathematical Patterns in Nature*, has a textbook and workshop project book written by Frederick P. Greenleaf, who created the course [7, 8]. It was decided to translate this course from the lecture format, to a small-group format with classes run by graduate students and enrollments limited to 15 or 16 students.

### **Course Format: No Lectures**

The approach that we took was to take the existing course, *Mathematical Patterns in Nature* and run it in two formats during the same semester: the lecture format described above and a small-group format without formal lectures. Adopting a new format for a course raises the question of contact time. Should the new format be designed to have the same amount of contact time as the lecture format?

Discussions led us to small-group classes that consisted of two 100-minute sessions. As a consequence, students enrolled in the small-group sections received 50 minutes less contact time each week than students in the lecture sections. In a 14-week semester, this amounts to 11.7 hours of contact time that students have free for other activities. This is a strong reason students find this new format appealing.

The small-group sections were able to cover the same material in a shorter amount of time, primarily due to the active nature of the classroom sessions. In a typical lecture, students watch the professor describe a topic in considerable detail and do a number of examples, but they usually do not work on or discuss problems themselves. Students will not attempt any close interaction with the material until they are out of the lecture and doing homework. This is not true for the small-group classes, which the Faculty Steering Committee felt removes a lot of the redundancy built into the traditional lecture format; whereby, students are not required to engage in class work even if they are present in the lecture hall, and spend time in the single weekly workshop reviewing material they watched the professor do in the lecture. Indeed, the attendance is much better for the small-group sessions since, among other reasons, it is possible to take attendance in a class of 15 students. Students also come to class knowing that they are

going to work with other students. This compels the student to come prepared and ready to engage their fellow students and be engaged themselves.

Kenneth Goldberg introduced us to masters and doctoral candidates in mathematics education who had a particular interest in small-group learning. They were some of the instructors who taught the small-group format, while the remaining sections were taught by graduate students from the Mathematics Department. In addition to the teaching experience that the graduate students from the School of Education gained, the graduate students from the Mathematics Department had the opportunity to engage in discussions about teaching with students pursuing studies in education.

### **Size of the Experiment**

In spring 1999, we directly compared the two formats by offering 126 seats in lecture version of *Mathematical Patterns in Nature* and 120 seats in a small-group version devoid of formal lecture. At final enrollment, 98 students chose the lecture version and 120 students chose the small-group version. The *only* sections that were filled to maximum capacity were the small-group sections.

### **Sample Activity**

The curriculum for the course includes growth and decay problems, such as problems dealing with the growth of money under compounding. Students are asked to visit neighborhood banks and ask for current rates on 3-month CDs and savings accounts. The instructor for the course gives the students 5 stocks and 5 mutual funds, in addition to 3-month CDs and savings accounts, to choose from and make a hypothetical portfolio, assuming they had \$10,000 to invest. Each week, the current stock price is recorded from the daily newspaper. Students calculate the present value of their portfolio each week.

### **Assessment**

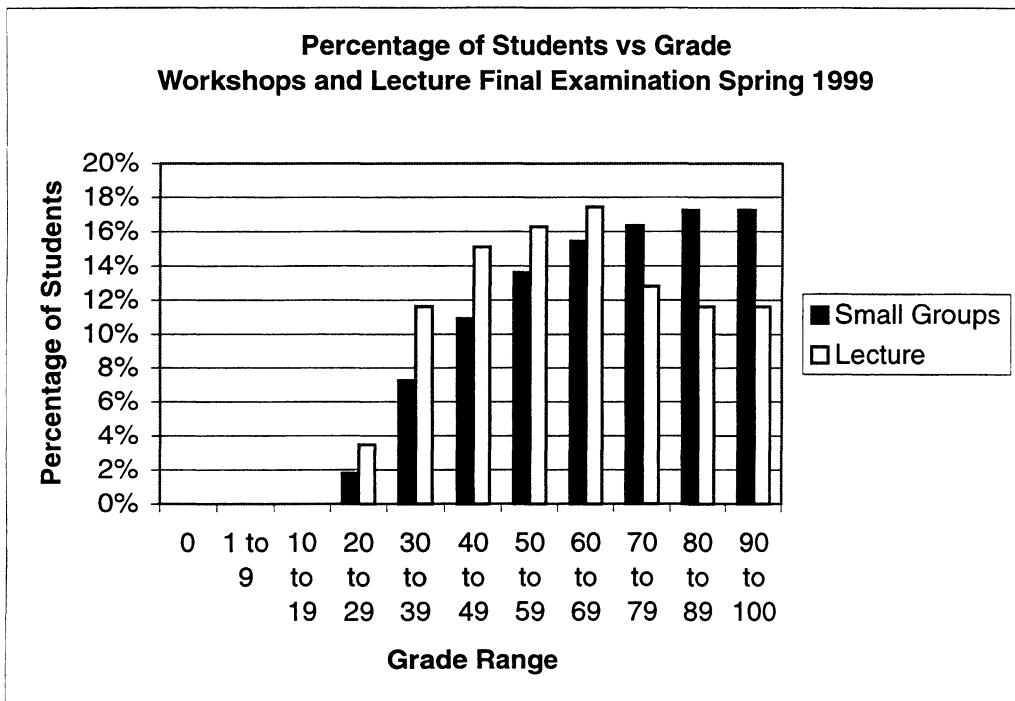
Early in our planning for the small-group format, it was decided that *all* students enrolled in *Mathematical Patterns in Nature* in the Spring 1999 semester should take the same final exam, regardless of format chosen. Exams were given at the same time and day for both groups. The syllabi for the lecture and small-group sections of *Mathematical Patterns in Nature* are identical, and they conducted essentially the same lab workshop projects. A comparison of the exam scores was then used to compare



effectiveness of the two formats (see below). Further data to be considered includes: gender, class, school, and Math SAT scores. In addition, a pre-test was given at the beginning of the semester to get an idea of the knowledge that students brought into the class. These results will be published in the future.

### Results of the Final Examination

Students in the lecture and workshop versions of the course took the same final examination. The exam was written by Frederick Greenleaf, who taught the lecture version of the course in spring 1999.



A graph of the percentage of students in the lecture receiving a grade within a 10 point-wide range was looked at and compared to the same data for all students in the small-group version of the course. This data is presented in the graph above. A greater percentage of the students in the workshop version of QR got scores of 70 or higher, while a greater percentage of students in the lecture version of QR got scores of less than 70. Specifically, 50% of students in the small-group based course achieved a grade of

70% or better on the final examination, as opposed to 37% of students in the lecture-based course.

### Future Work

Results of the assessment activities outlined above will be published, based on the data that will be taken in the Fall 1999, Spring 2000, Fall 2000, and Spring 2001 semesters. Final exam results and student responses will be analyzed to see if students consistently prefer and do better in the small-group format.

Further, in the summer of 1999, a small-group version of another Quantitative Reasoning course, *Mathematics and the Computer*, was offered to 30 students in two sections. In spring 2000, the small-group version of *Mathematics and the Computer* will be offered with 60 seats distributed among 4 sections, thus maintaining a class size of 15. This will extend the small-group pedagogy to a second QR course. ■

### Bio

Andre Adler is Coordinator of the Foundations of Scientific Inquiry program in the Morse Academic Plan. He holds a Ph.D. in Physics from New York University and has taught in the Physics Department, as well as courses in Mathematics and the Physical Sciences in NYU's Core Curriculum, the Morse Academic Plan.

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## MATHEMATICS IN HANDS-ON SCIENCE FOR LIBERAL ARTS STUDENTS

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We describe a number of experiments from the courses called, *General Science 9*, part of the science program for elementary education majors at Brooklyn College. These courses provide hands-on learning experiences for students who are insecure and weak in science and mathematics. Quantitative thinking is a central element in most of the students' work. Mathematics is taught in a concrete and intuitive way, as a direct outgrowth of their needs; first, in analysis of data, and second, in discovering underlying theory. The science program has been developed through cooperation among faculty from the School of Education and the science departments.

This paper examines the synergy between teaching science and teaching mathematics, with special reference to the education of non-science majors. Our discussion grows out of experiences developing and teaching inquiry-based courses for an audience of elementary education majors.

In a traditional introductory science course, particularly in the physical sciences but to some extent also in the biological sciences, mathematical treatment of the subject is taken for granted. When it comes to science for the liberal arts major, however, it is often argued that mathematical treatment is inappropriate, or at least not feasible because students' skills are weak. Thus, texts emphasize conceptual learning [1, 2]. It is nevertheless true that the mathematics that students are supposed to have learned, in high school for example, or in remedial work in college, should prepare them for a reasonable level of quantitative thinking in connection with science or, indeed, with other subjects as well [3]. Moreover, the argument that science is intrinsically mathematical, while out of fashion in some circles, nevertheless retains merit – particularly if one accepts the view that science is fundamentally theory-based, and that theories are expressed mathematically. Thus the science class, even one that is dominantly hands-on, should

proceed from experiment and analysis to the construction and testing of theory, the latter expressed in mathematical terms.

Pursuing this objective and struggling with student weaknesses, we find that new ways of approaching math education present themselves. Manipulations with numbers that are the result of measurement (and so have limited accuracy) obey different rules than manipulations with exact numbers. Scientific notation, powers of ten, and metric prefixes all become useful tools, not annoying obstacles. Geometrical relationships and theorems follow from hands-on measurements, reviving the root meaning of the word “geometry.” The utility of much of algebra turns out to be exaggerated, but some simple algebraic operations are constantly in demand, and become second nature. The concept of the “function,” stripped of abstraction, is more important than anything else.

Below, we give two examples of combined math/science units which are treated in the course *General Science 9*, part of the science curriculum for education students at Brooklyn College. The New York Collaborative for Excellence in Teacher Preparation (NYCETP) supported this curriculum as it grew out of extensive collaboration among faculty in the School of Education and the science departments.

Students majoring in early childhood and elementary education take a series of science courses, beginning with the 8-credit science component of the Core Curriculum. The Core is required of all undergraduates, and the science component consists of four survey courses: two credits each in Chemistry, Physics, Biology, and Geology. In addition to the Core, education students take Gen. Sci. 9 (four credits), Gen. Sci. 10 (three credits), and Gen. Sci. 20 (two credits); the latter two paired with courses on pedagogy in science, math, and technology. Gen. Sci. 9 represents a series of courses from which the students choose one. At present, the following courses are available:

- General Science 9.1: Geophysics
- General Science 9.2: Light and Visual Perception
- General Science 9.3: Biology and Chemistry of Everyday Life

A fourth course, General Science 9.4: Studies in Paleobiology, is in preparation.

These courses meet for five hours per week in a room containing laboratory tables and seats for class discussion. The group is small, up to 24 students. Learning is based primarily on hands-on activities that engage students with observation of the natural world. During the class period, students go back and forth from lab work and collection of data, to working individually or in small groups on data analysis, to writing reports, and to class-wide discussion led by the instructor. Thus, the class models, at a higher level, the kind of science classroom that is desired at the elementary school level.

A good deal of the student's time is spent writing a lab report, and this is largely done in the classroom, not at home. Thus, he/she has the opportunity to go back to the lab table, or to the data, to re-evaluate or repeat procedures. The final report, which sometimes represents 6 or 8 hours of work, can be an impressive portfolio of achievement. Grades on lab reports make up almost half the student's final grade.

*General Science 9* provides a realistic model of a science research lab, where student-scientists first informally investigate (play with) a new phenomenon, then set up systematic and quantitative measurements, then analyze (play with) the data, and finally, look for explanations of their results in terms of simple theoretical principles.

Students in this program are quite weak in science and mathematics. They may have had some high school algebra, but remember very little of it. They heartily dislike mathematics, are certain that they are very poor math students, and cannot see any reason for studying it at all. Some students come into the class hating science, in some cases as a consequence of their experience in the Core course. Some feel that science can be interesting, but all feel that science is not for them: it is too hard and too mathematical. On the whole, these students represent the norm among those Brooklyn College students who do not major in math or science.

Observations over a period of about six years suggest that these students' major weakness is in abstract thinking, that they have done very little of it, find it stressful, and tend to surrender to their stress. Consequently, we attempt in these courses to approach subjects, both in science and math, as concretely as possible, and to develop abstract ideas gradually as an outgrowth of concrete studies. Algebraic work is largely limited to

equations like “ $ab = c$ ,” or sometimes “ $ab = cd$ ,” but students must work with these equations frequently, exploring them in a wide variety of forms and contexts.

### The Shadow Experiment

The shadow experiment [4,5] in Gen. Sci. 9.2 is shown schematically in Fig. 1. The light source is a lamp with a non-frosted bulb. The filament is oriented vertically (the experimental layout is a horizontal plane), so that the source is almost a point. The “object” is a card that the students make (about 8 cm wide), and it casts a shadow on the screen. Students are to investigate how the width of the shadow,  $S$ , varies as things move. The lamp has a reflector, so that initially there is a complicated umbra/penumbra. After some observations and discussion, the reflector is covered with black paper to simplify experimental conditions (to create the point source).

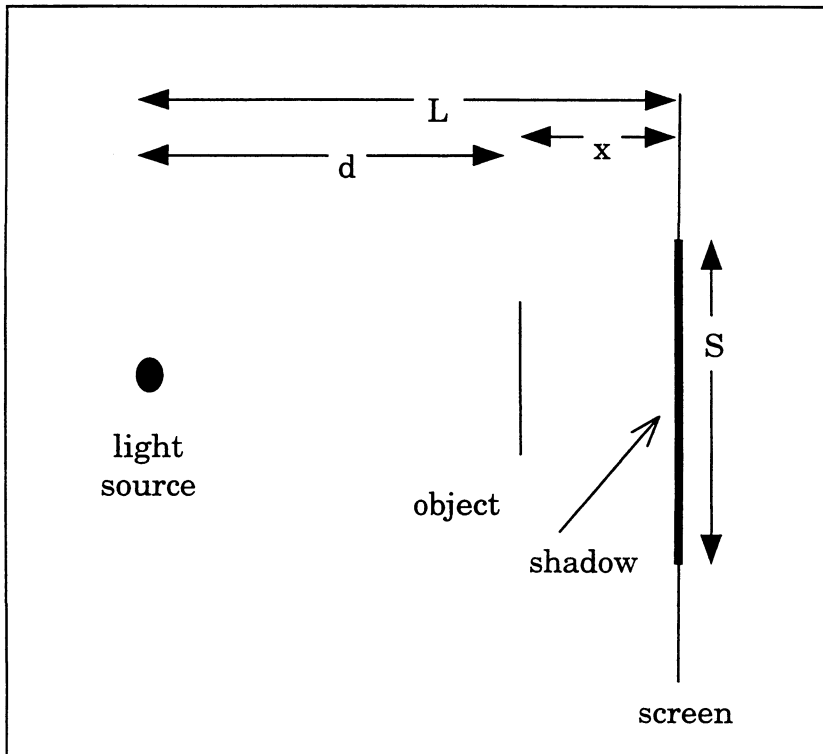


Fig. 1 - The shadow experiment

Students first spend some time playing with the pieces to see how the shadow size changes. We then get together to discuss how to control variables systematically. It is useful to disabuse the students of the notion that controlling the variables is a straightforward or obvious process — as is typically implied in discussions of “the scientific method.” In this experiment, there are three variables ( $d$ ,  $x$ , and  $L$ ). Although it is clear that only two of the three need be studied experimentally since they are not independent, it is not at all easy to convince students of this point. Furthermore, once we agree to study two of these variables, one choice of two variables will make interpretation of the experiment much clearer than other choices. While students are not led through a full mathematical discussion of these points, they do begin to see, after working on the experiment for some time, something of the subtlety involved in planning research.

Students do two experiments, one keeping  $d$  fixed and varying  $L$ , the second keeping  $L$  fixed and varying  $d$ . The graph of  $S$  vs.  $L$  is their first example of a linear relationship. They plot the points, draw the best straight line close to the points and through the origin, and then find the slope using one point on the line. All this is somewhat new, since most of their prior graphing experience was with integers. Working with measured numbers, with, say, three significant figures, is unfamiliar. A line that fits points only approximately is also something new. We create an entirely new kind of arithmetic when we use measured numbers.

We stress that linearity is a fundamental relationship, the one to which others are usually compared. Important real-life problems depend on whether a functional relationship is linear or not (the biological effects of low level radioactivity, for example). Students may have spent hours analyzing straight-line graphs using slopes and  $y$ -intercepts, but they have not been told the significance of what they have done. A linear relationship can be expressed in many ways: as a graph (which is the first way that we see it here), as a proportion, or as an equation. We see all of these in the shadow experiment.

Data for fixed  $L$  and variable  $d$  are also plotted. The graph of  $S$  vs.  $d$  represents a decreasing function. A smooth curve fits the points rather well. Students also plot  $S$  vs.  $1/d$ . This is quite a bizarre step to them, and they cannot appreciate it without considerable background work. To this end, students receive homework assignments in

which they start with equations like,  $y = 3/x$ ,  $y = 0.5/x$ , make tables of  $x$ ,  $y$ , and  $1/x$ , and plot  $y$  vs.  $x$  and  $1/x$ . By doing a number of simple examples, they see how the  $1/x$  graph comes out as a straight line. (In fact, a few students need practice like this even for the linear relationship, and they do homework problems on  $y = 2x$ ,  $y = 0.4x$ , etc.) Thus, we learn that a decreasing relationship may or may not be an inverse proportion.

Teaching this inverse relationship probably would not succeed if it were done only in this experiment, but there are two or sometimes three other places in the course where it comes up. One is in an experiment on parallax which I won't elaborate, where the parallax shift is inversely proportional to the distance of an object from the viewer. Another is in the ripple tank experiment, discussed later.

Data in the shadow experiment are also looked at as direct and inverse proportionalities:

$$S_1/L_1 = S_2/L_2 = \text{etc.}, \quad \text{and} \quad S_1d_1 = S_2d_2 = \text{etc.}$$

Results are usually convincing, but small discrepancies lead naturally to a discussion of measurement uncertainties, round-off, and significant figures.

There are two more follow-ups to the shadow experiment, aimed at "explaining" the data, as the next step beyond analysis. Here, one hopes to make the point that science, including experimental research, rests on theoretic underpinnings. One seeks simple principles to explain observed relationships. First, students are asked to explain qualitatively why  $S$  increases with  $L$  by simply drawing two diagrams of the apparatus, one with large  $L$  and one with small  $L$ , with  $d$  held constant (as in Fig. 2). Before they can do this, they have to come to the understanding that the pairs of  $P_1$ ,  $P_2$  and  $Q_1$ ,  $Q_2$  determine the width of the shadow, since light rays travel in straight lines. We generally come to this conclusion in a group discussion without too much prodding from the instructor.



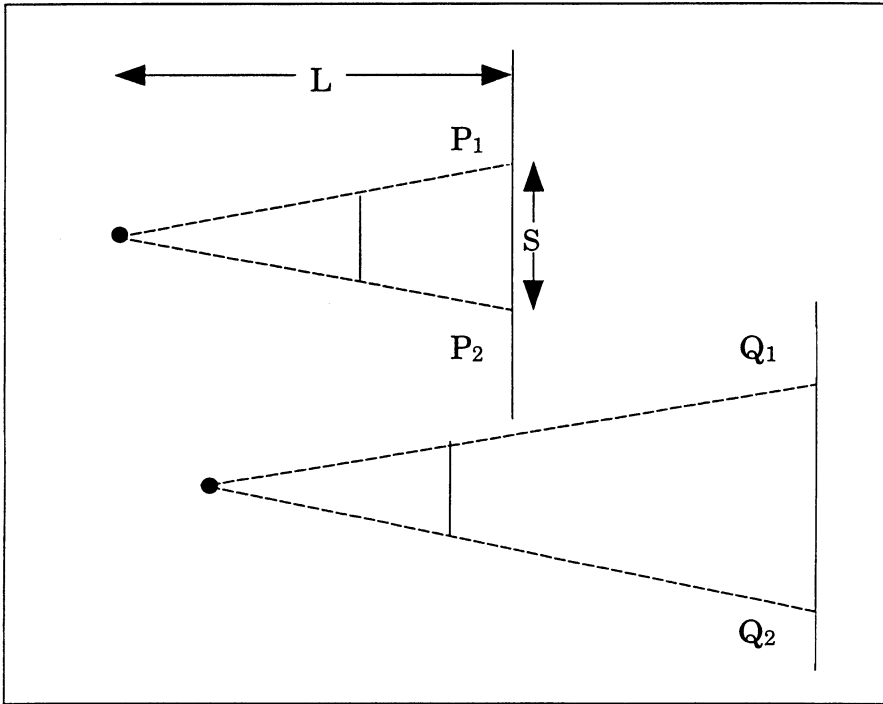


Fig. 2 – Student exercise to demonstrate qualitatively the dependence of  $S$  on  $L$

But in the next step, in which students must draw figures to show the increase with  $L$ , they are surprisingly poor. They don't draw diagrams accurately, they don't draw lines straight, they fail to keep other lengths constant, and they don't know that they should make  $L$  very different in the two cases in order to demonstrate clearly the increase in  $S$ . Significantly, it is not natural to students to draw a diagram in a schematic form, as is done in Figs. 1 and 2 here, for example. They prefer to draw realistic diagrams, with perspective, and showing various details of the apparatus that are irrelevant to the scientific or mathematical questions at issue. This illustrates their unfamiliarity with abstraction. We note that this kind of diagrammatic analysis is the kind of "problem-solving" skill that math reform tries to introduce in the early grades [6], and an exercise such as this, combined with real lab observations, would be a useful example. Whether students can successfully develop these skills remains to be seen.

Finally, we deduce the quantitative relation in this experiment by using the diagram in Fig. 1, and the proportionality of sides in similar triangles:

$$S/L = w/d,$$

where  $w$  is the width of the object. Deriving this equation calls for a detour into some geometry, discussed below. The equation for  $S$  is then used to show the proportionality of  $S$  to  $L$  and to  $1/d$ , to deduce the slopes of these two straight lines, and to compare them with slopes found from the students' graphs.

Students come to understand proportionalities by working with them repeatedly. Many other hands-on subjects in science or math suggest themselves for the study of proportions: mass/density/volume, time/speed/distance, scaling on a map, unit conversion, etc. They are not what might be considered "college math," but it is well-known that college students today are poor in these areas [7], and the science class should be used to bring home the issue.

### Experiments with Angles

Both Gen. Sci. 9.1 and 9.2 require students to work with relations among angles. We study the laws of refraction and reflection of light in both courses. In 9.1, they serve as analogs for refraction and reflection of seismic waves. Other uses of angles are discussed below. Students have some feel for angles on a piece of paper, but not in real space, and they have little awareness that angles are the key to visual perception. A number of exercises are used in these courses to give students an understanding of angles on a concrete level, as opposed to a more abstract or set-theoretic treatment of the subject. The close connections relating angles, similarity in geometric figures, and proportions leads to reinforcement in the study of these subjects.

Similarity is demonstrated by having students measure the sides of similar geometrical figures and verify the proportionality of corresponding sides. Angular functions are defined by having students measure lengths on paper, and determine appropriate ratios. They construct diagrams like those in Fig. 3 to study the radian measure of an angle, the "blip" ( $b/h$  in Fig. 3 (ii)), and the sine. We graph measurements gathered from the whole class, and they discover that (a) the radian measure is

proportional to the degree measure, and (b) the three functions are approximately equal for small angles.

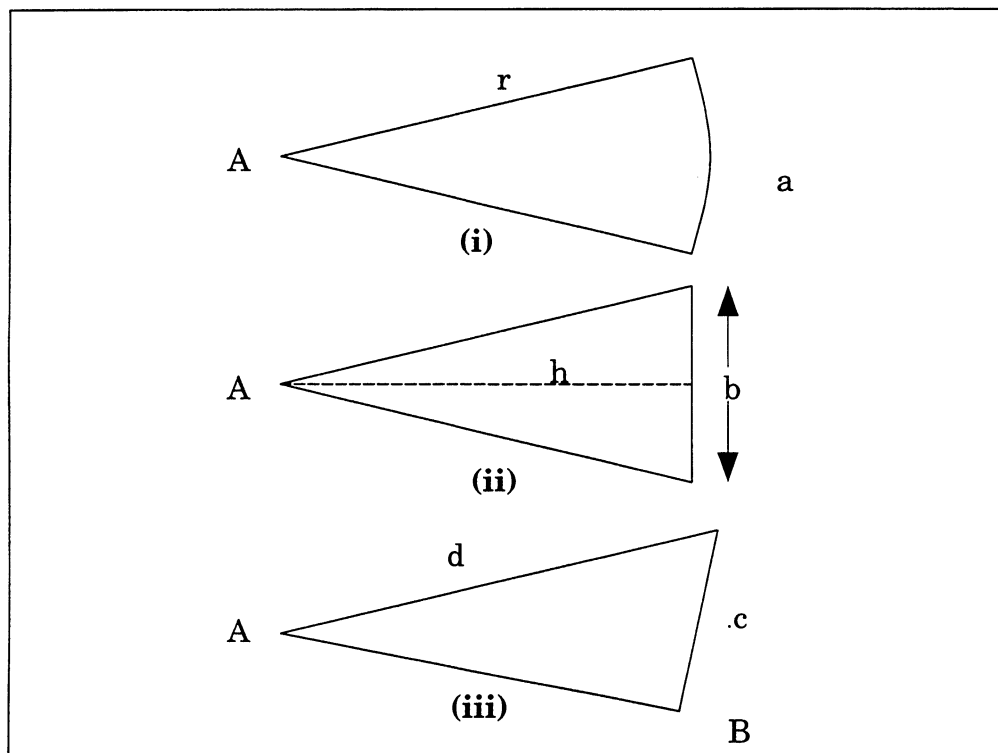


Figure 3 – Definitions of angular functions: (i) radian, (ii) blip, (iii) sine

The blip is used in an experiment on apparent size. Students hold up cards of different sizes ( $s$ ) and place them at different distances ( $d$ ) from the eye, so that they appear to be the same size. Students then verify that the ratios  $s/d$  are the same — either by calculating the ratios or by plotting  $s$  vs.  $d$ . The ratio  $s/d$  is the blip, size of the object divided by the distance from it to the eye. The idea that the eye measures angular size is quite new to students. (Indeed, there are usually one or two students in a class who simply cannot get it: they cannot abstract from the actual size of the object to the apparent size, and insist that the larger card appears larger than the smaller one, even when its apparent size is the same, or much smaller.)

We follow this experiment with the idea of using your finger at arm's length as a rough measure of the angular size of distant objects. Students can estimate, for example,

the angular size of a car at a distance of a block, and then check their result by pacing off the length of the block and noting the size of the car. Similarly, we can observe the near equality of the apparent size of the sun and the moon, and then calculate the blip from given astronomical numbers.

We use the sine of the angle in an experiment on refraction. This is a typical geometrical optics experiment in which one traces the path of a light ray through a rectangular block of lucite. I omit details of the setup; students obtain the angle of incidence and the angle of refraction for a ray emerging from lucite into air (Fig. 4). They then plot  $A_{\text{air}}$  vs.  $A_{\text{luc}}$  and obtain points that are fit by a straight line fairly well, up to  $A_{\text{air}} = 45$  degrees. Above that angle, the points veer systematically away from the line. They then find the sines of the angles, using our measured graph, plot  $\sin A_{\text{air}}$  vs.  $\sin A_{\text{luc}}$ , and get a straight line close to all the points, verifying Snell's Law of Refraction.

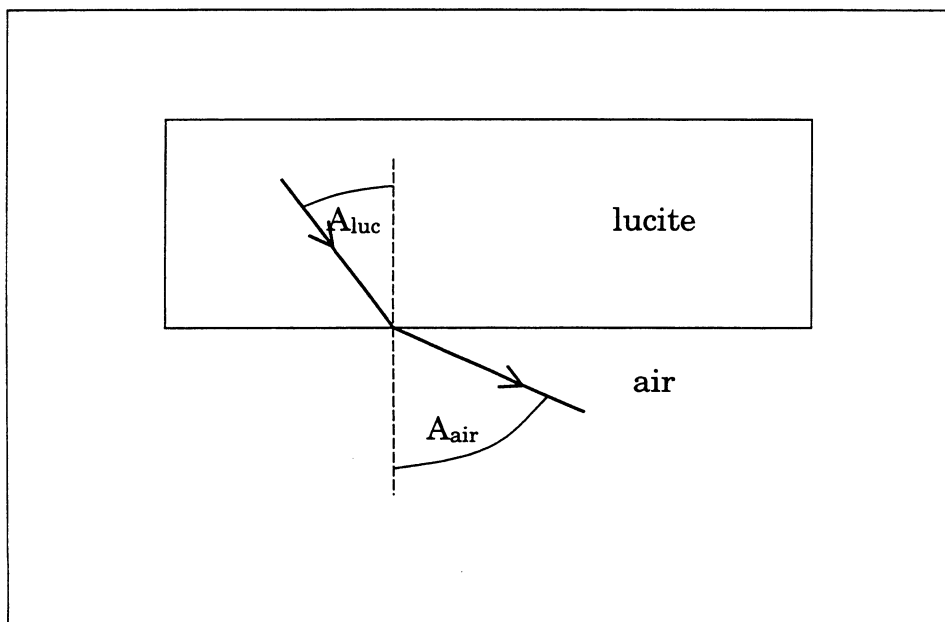


Figure 4 – The refraction experiment

Toward the end of the term in Gen. Sci. 9.2, we do two experiments that introduce the different colors of the spectrum and the wave character of light. The first is a dispersion experiment, in which we use helium-neon lasers with three different wavelengths, 544, 594, and 612 nm (green, yellow, and orange) [8]. The lasers are placed in a fixed stand and the light is refracted through a prism, striking a screen about 4 m away. We measure the shift in the refraction angle from one beam to the others. These shifts are small angles (up to .02 radians), and students see that they could not be measured with a protractor. We can only use the blip, which is easily determined from the shift of the laser point on the screen; we then recognize that the blip and the radian are equal for small angles, and then convert radians to degrees using an experimentally determined constant.

The last part of the course occupies at least 6 hours of lab time. It involves the two-slit experiment with light, in parallel with the analogous ripple tank experiment which looks at the interference pattern with two wave sources in water. Here, the fundamental equation, applying to both experiments, also involves the sine (Fig. 5):

$$\sin A = m\lambda/d,$$

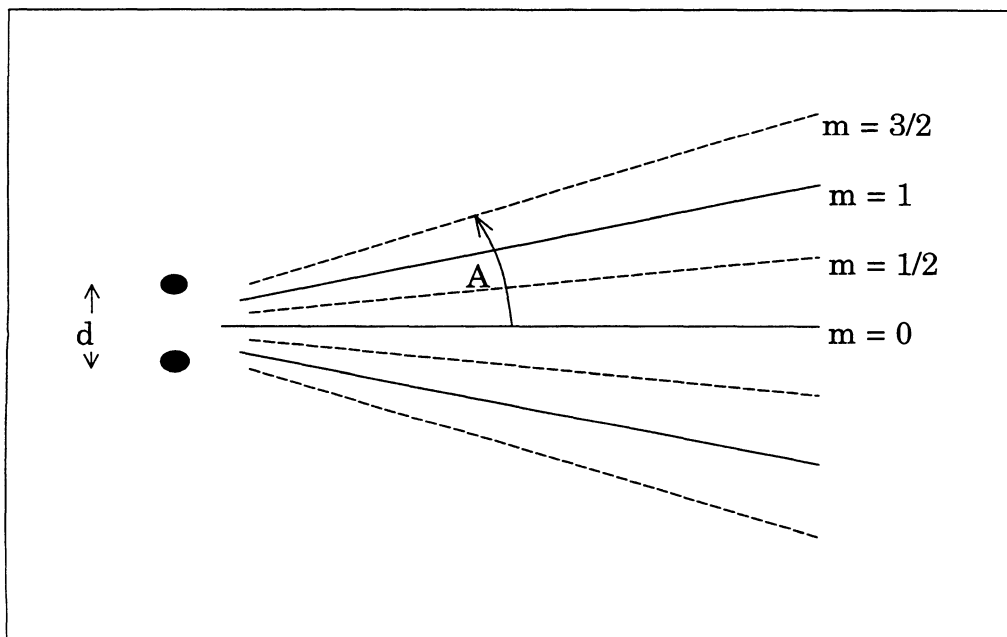


Figure 5 – The interference experiment using light waves or water waves

where  $m$  represents the order of the interference fringe ( $m = 0$  for the central maximum,  $m = 1/2$  for the first destructive interference point,  $m = 1$  for the first constructive interference point, etc.),  $d$  the spacing between the two sources, and  $\lambda$  the wavelength. The two-slit experiment which established beyond doubt the classical wave character of light is one of the most important experiments in the history of physics. Because of the subtlety of the phenomenon of interference, indeed because of the subtlety of the concept of waves altogether, it seemed essential to couple this experiment with the more concrete and tangible experiment with water waves. It is immensely instructive for students to try to see the parallel between the two experiments, even as the surface features of the two experiments differ so markedly; including the fact that, in the ripple tank we mark the line of destructive interference whereas with light fringes, we measure to the points of constructive interference.

At present, we are not able reliably to measure the wavelength of the water waves in the ripple tank. However, we can measure the angles up to  $m = 1/2, 3/2$ , and  $5/2$ , choose three different values of  $d$ , and verify the dependence of the angle on  $m$  and  $d$  (see Fig. 5). The angle is drawn to the center point between the sources and is measured with a protractor. The sine of the angle is determined from our previous studies.

In the case of the light experiment, we use lasers with four wavelengths (the three used in the dispersion experiment, plus one at 633 nm). The slit-spacing  $d$  is fixed. The interference pattern is on a screen about 2 m from the slit, and the distance from the  $m = 4$  bright spot on one side, to the  $m = 4$  bright spot on the other side is measured. Then, the angle here is determined from the blip, and we again replace the blip by the sine. We usually get an impressive straight-line graph of angle vs. wavelength.

## Conclusion

The purpose of these experiments is to teach subjects in science -- visual perception, refraction, interference, etc. Along the way, mathematics is introduced and reinforced from many directions. The mathematics is not an abstract entity created by a book or a teacher, but a real thing in front of the student, and it is *the* tool the student needs to make sense of his/her findings. Furthermore, the same mathematical concepts turn up, perhaps unexpectedly, but repeatedly through the term, to the point where the student begins to see that certain important things are happening. It is not a matter of

drill vs. conceptual learning [9], but of the student's active and continuous involvement with the concept.

Similarly, one can envisage concrete, hands-on approaches that are continually tied to applications in science other subjects, and to many fields of mathematics, including statistics, and plane and solid geometry, etc. Where such an approach cannot be envisaged, perhaps an *ab initio* evaluation of the appropriateness of that field in the curriculum is called for.

Finally, we observe that the approaches being discussed here should be effective at earlier stages in the educational process. It is then possible that the more hands-on and concrete development of mathematics in the early years, especially with constant reinforcement in the science and social science classes, may allow a more secure growth of abstract thinking skills in the teen years. Thus prepared, a more sophisticated college student, adept at abstract analysis, may be appreciate and be given the deeper and more satisfying experience in science and mathematics that he/she deserves. ■

## Bio

Michael Sobel is Professor of Physics at Brooklyn College of CUNY. His interests are in theoretical nuclear physics, nuclear arms control, inquiry-based science for liberal arts students, and mathematics reform.

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# **BRIDGING THE GAP BETWEEN SCHOOLS AND NON-FORMAL SCIENCE INSTITUTIONS: USING NEW YORK CITY'S NON-FORMAL RESOURCES TO TEACH SCIENCE**

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Effective science teaching and learning needs to take place in an environment in which the formal and non-formal worlds of science combine their expertise and resources. Science learning and ultimately, scientific literacy for all depends on the teaching that occurs both in schools and in non-formal settings. As we move towards the attainment of scientific literacy for all, it is becoming more imperative that we recognize and utilize the media, industry education programs, non-formal science centers, museums, and other science learning outlets as valuable segments of our nation's science education infrastructure. This paper describes the context, rationale, and outline of the non-formal science education course developed at New York University under the auspices of New York Collaborative for Excellence in Teacher Preparation (NYCETP) and the subsequently developed non-formal science education specialization.

## **Introduction**

Non-formal science education sites encompass unique settings where information, stimulation, and experiences are provided almost entirely through objects, their interpretative display and more recently, manipulation of these objects. Science learning and ultimately scientific literacy for all depends on the teaching that occurs both in schools and in non-formal settings. As we move towards the attainment of scientific literacy for all, it is becoming more imperative that we recognize and utilize the media, industry education programs, non-formal science centers, museums and other science learning outlets as valuable segments of our nation's science education infrastructure [1,2]. Serious gaps currently exist in our educational infrastructure that limit the attainment of scientific literacy. A major gap is the lack of communication and collaboration between the many agents that are involved in teaching science. As educators, we need to form strategic partnerships between schools and institutions that offer non-formal learning of science and to view non-formal learning resources as a key

part of the educational system, systematically incorporating them into our science education infrastructure [1,2].

In spite of our focus on standards and inquiry learning, students often do not get first hand experience of natural phenomena. The out of school community is often rich in the resources to provide such exposure. Science museums, zoos, etc. present phenomena in the form of exhibits that are interactive, with a focus on enabling visitors to explore, manipulate, and experiment. Science teachers are often overwhelmed with the demands of covering a curriculum full of abstract principles. As a result, and regardless of what the state or national standards dictate, students are rarely given an opportunity to learn science in context. Non-formal institutions can rectify this situation.

Over the past 10 years and through my involvement with the New York City museums and science centers, I realized that these non-formal science sites had rich educational programs and resources that could be made use of by public school science and mathematics teachers to supplement and enhance their classroom teaching. Using my relationship with these institutions and with the support of the New York Collaborative in Teacher Preparation (NYCTEP), I developed and began to teach a course that would introduce future science and mathematics teachers to this rich educational resource and the educational programs and staff involved.

Initially, NYCETP and New York University faculty compiled a list of Non-formal Science Education sites in New York City with a description of their education programs, locations, and accessibility to schools and the public. This information was then published as a sourcebook to use in the course entitled, *Using New York City's Non-formal Science Resources to Teach Science*, which is now taken by pre- and in-service teachers and forms part of our non-formal specialization. This sourcebook is continuously updated and expanded in cooperation with faculty, students, and teachers who are currently involved in this project. Concurrent with the development of the sourcebook, we conducted a national survey to determine the need for training in non-formal science education, the availability of current and future jobs in the area, and the required components of a graduate program in Non-formal Science Education as perceived by personnel presently involved in Non-formal Science.

We felt that it was time to take advantage of the non-formal educational resources that surround us. Doing so would bridge the formal and non-formal, non-intersecting systems to provide our populace with access to science and technology, an understanding of their influence on our daily lives, and thus make some inroads in achieving scientific and technological literacy for all. The course, *E14.2050: Using New York City's Non-Formal Resources to Teach Science*, was developed under the auspices of the NYCETP. This is an optional course in the Master's Program for science and mathematics education. In this class, students are able to take advantage of the multitude of scientific resources in New York City. The course is offered both during the academic year and in summer.

The course involves three components that are equally supportive:

- Structured group workshops during which the students meet with a member of the site's educational staff to learn how the resources and programs can be utilized by classroom teachers;
- Non-formal, non-structured visits to selected sites to see the educational exhibits and programs that are offered to the general public; and,
- Seminars at NYU during which the students and their instructor can discuss and individually reflect upon their visits to the sites, their programs and resources, and their usefulness to classroom teachers.

The first component of the course requires structured visits to various non-formal sites throughout the city, such as: the New York Hall of Science, Bronx Zoo, New York botanical Gardens, Children's Museum, Museum of Natural History, Prospect Park Zoo, Liberty Science Center, Wildlife Conservation Society Aquarium, and the Intrepid. Each visit exposes the student to the rich educational resources that can be used by classroom teachers to facilitate hands-on mathematics and science learning in their own classrooms. Students are required to spend 4-6 hours participating in a workshop and visiting various exhibits at each site. During the workshops, a member of the site's educational staff:

- instructs students on how the resources and programs can be utilized by classroom teachers;

- provides handouts and vital information regarding each exhibit;
- proposes ideas for pre- and post-visit activities;
- gives a one year membership to each student in the class.

The second component requires students to make at least one non-structured visit to a non-formal site. During this visit, students are asked to look for ways in which they can effectively use the information presented at the site in a grade 7-12 science or math classroom. Students are asked to share their findings with the rest of the class, thus exposing the students in the class to at least 10 additional non-formal sites.

The final component of the course requires each student to conduct research on non-formal science education. Students administer a set of questionnaires to either grade 7-12 students, parents, or grade 7-12 science teachers, and in a group, conduct an in-depth literature review regarding their specific population, as well as analyze the group's data. Previous research topics included: *"Improving the Educational Quality at Non-formal Education Sites," "The Value of Non-Formal Science Resources to Teachers of Science,"* and, *"Non-formal Educational Facilities Effect on and the Use by the Adult Learner and the Family."* One of our outstanding students presented her group's research at the annual meeting of the Association for the Education of Teachers of Science in Austin, Texas in 1999. Her topic was, *"The Educational and Social Value of Non-formal Science Education."* Exceptional research groups will be asked to present their work at the Sharing Our Success (SOS) Conference at NYU on May 24, 2000.

Combining theory, practical application, and using the city as a "living lab," teeming with educational and instructional resources, is the focus of the course. Allowing future teachers to make connections with the educational staff at these institutions, so that they can make personal contact once they are full-time teachers and want to make use of these resources, helps to bridge the gap between public schools and non-formal institutions.

As a result of the immense interest generated by this course and the results of our survey, we subsequently developed a masters program that includes the following elements:

- a) A rigorous New York State approved certification program for pre-service and in-service teachers of Biology, Chemistry, or Physics, grades 7 – 12.
- b) Visits to various science institutions in the metropolitan area to become familiar with non-formal educational programs for:
  - Possible inclusion in classroom curriculum, and;
  - Information on how to plan an effective and educational trip, whether by using the institution's educational workshops or by composing self-guided tours.
- c) A six-week, full-time or a six-month, part-time internship at a science institution that will allow the teacher to focus on the daily activities of the institution's education or exhibit departments.
- d) A museum education seminar.
- e) A course on measuring the outcomes of science teaching.
- f) A content course taken simultaneously with a hands-on workshop at a science institution in the same subject.

By providing training in both formal and non-formal environments, graduates will have the skills necessary to bridge both educational systems. Whatever environment they decide to work in, these graduates will be trained in the required content, pedagogy, and non-formal science research and evaluation required by both systems.

### **Where Do We Go From Here?**

We view this as the first step in the development of an academic home for non-formal science education. Future developments still require careful study and analysis. We need the kind of input provided by Friedman [1], Honeyman [2], and others as we expand our vision to train leaders for the rapidly growing field of museums, science and technology centers, zoos, aquariums, community activity centers, and multimedia and mass-media educational enterprises.

Our future plans include:

- a. Further discussion with faculty in science, psychology, education, museum studies, communications, and visual and graphic arts to

develop a doctoral program to be taught by faculty from all these disciplines.

- b. Strengthening relationships with non-formal institutions both globally and in New York City. It is anticipated that the institutions in New York City will provide daily research sites, "real world" experiences through practicum and internships, part-time employment, and avenues for the evaluation of teaching and learning in non-formal science. They will be a focal point for research, and formative and summative evaluation as we develop the curriculum. Faculty in institutions outside of New York City will be consulted for input, serving as readers and advisors on doctoral committees, and as consultants as we advance our research, evaluation and funding agenda for non-formal science education. ■

## Bio

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# **COMBINING THEORY AND PRACTICE IN THE TEACHING OF SCIENCE: A COLLABORATIVE PROGRAM BETWEEN THE CITY UNIVERSITY OF NEW YORK AND THE AMERICAN MUSEUM OF NATURAL HISTORY**

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The National Science Education Standards contain several mandates that share the use of alternative and creative experiences in the teaching of science at all levels. An important feature of these standards is the call for learning settings and environments different from the traditional classroom in order to enhance student interest and participation in the learning process. New York City is rich in institutions that are ideal for the implementation of effective science teaching through the use of informal resources. This article uses the American Museum of Natural History as a prime example of this.

## **Introduction**

The American Museum of Natural History is not only an important cultural resource, it is perhaps the most integrated, informal educational resource in the city, since its exhibits and collections deal with many scientific disciplines. This makes it an ideal integral component of a science teacher preparation program. Its use provides a great opportunity for stimulative and interactive explorations as a means to develop and practice inquiry in the teaching of science, in response to the mandates of the National Science Education Standards [1].

The Museum's new halls and exhibits contain activities that fit perfectly in the implementation of hands-on tasks advocated by the standards. Among the activities in the Gottesman Hall of Planet Earth are interactive opportunities to learn difficult concepts in physical science not typically found in a school setting [2].

## **A Collaborative Opportunity**

The alarming prediction of shortages of science teachers in New York City has prompted the City University of New York to develop a joint program with the New York City Board of Education. The Teaching Opportunity Program Scholarship (TOPS) was designed to bring individuals with outstanding science content preparation into the classrooms of the largest school system in the country. Applicants were chosen based on

their academic records, recommendations, and a short presentation of their teaching interests and styles.

The incentives for attracting qualified applicants have included a paid summer internship, assured employment in a public school beginning in the fall semester, and a tuition-free masters degree offered through a CUNY college.

Lehman College is one of the three participating colleges in the program; our commitment has been to help the public school system by placing our science teacher-scholars in the Bronx and Manhattan. The three phases of the program at Lehman College have consisted of participants' preparation at various levels:

- An intense summer program combining pedagogical preparation with field experience in teaching.
- A series of workshops during the fall semester to discuss issues in classroom management, lesson planning, professional development, and teaching strategies.
- A carefully designed graduate program leading to a masters degree and New York State certification in teaching various sciences.

The need to combine theory and practice has been addressed from the earliest stages of the program. During the summer internship, the participants were actively engaged in developing lesson plans through the use of technology, such as the internet, and software integration of content.

The participation in a three-day institute at The American Museum of Natural History during the summer internship paved the way for a collaborative effort between the museum and the City University of New York. Some examples of student work produced during this institute contain lesson plans that actively incorporated use of the halls. Among them were: open-ended expeditions dealing with extinction; others were about uncertainties in our knowledge about dinosaurs; and, others were structured expeditions about adaptation.



## **Curriculum Development Using the Museum**

The first result of the collaboration has been the development of a course utilizing the Museum as a resource for teaching life, earth, and space science. This course has been incorporated into the academic preparation of the participants by becoming a required course for their masters degree.

The course is designed to introduce the teacher-scholars to the use of the Museum as a place for learning science as professionals and for teaching science to their students. It is divided into three modules that are aligned with New York State Standards for the Living Environment (Life Science), and the Physical Setting (Earth and Space Science).

The course is being taught by a group of teacher educators and Museum scientists who have designed sessions that include curriculum resources, laboratory activities, study in specific exhibit halls, and responses to teacher's guides and films. The Museum is ideally equipped to serve as a resource for curriculum development in various scientific disciplines. The participants select the module that most closely supports their current teaching situation. Presentations of their resource file and a portfolio are required, in addition to the planning and execution of a Museum field trip with a small group of their students. The portfolio includes entries that illustrate the teaching unit selected and presented at the end of one of the modules. For example, biology and environmental science teachers might select the Life Science module to develop their teaching project. The Life Science module contains guided study in the Hall of Vertebrate Origins to study fossils as evidence of the historical record. The teacher can use the exhibits of fossil excavation to introduce fossil classification according to the way they are formed. The teacher can also use a cladistics activity from the teacher's guide to the Hall of Invertebrate Origins to demonstrate the principles of classification used by systematic biologists. Another lesson can use research in biodiversity to answer questions such as: What is biodiversity? What have we lost, what are we losing? What are some conservation strategies and solutions?

Each module is taught over a period of four sessions. The module begins with a content session taught by a teacher educator and a Museum scientist in the field of science of the particular module. The second and third sessions are taught by instructors

from the Museum Education Department, and the Board of Education who have implemented or developed Museum support curriculum labs, or Regents level courses. All instructors participate in the final session of each module and in the evaluation and assessment of the participants' work at the end of the course.

### **Additional Incorporation of the Museum in Teacher Preparation**

The second outcome of the collaboration with the Museum has been the restructuring of the research component of the Masters degree in science education at Lehman College. As the graduate advisor in science education, I have been exposed to various types of theses prepared by students in the traditional setting of our program. The majority of the topics have to do with statistical analyses of performance, or with the influence of societal factors on student achievement in science, etc. Although these studies may all have scholarly merit, they have seemed somewhat esoteric, and to lack a measure of relevance to our student population.

The first part of the thesis can be done in the traditional setting, although the students involved would only be science education majors, as opposed to being part of a larger group. The students will demonstrate competence in implementing principles of research by successfully completing the introduction to a project of proposed research in their chosen field of science (chapter I). The desired project is one that actively and creatively utilizes the Museum as the means to develop science instruction having the following features: a) it is standards-based; b) it encourages exploration; c) it is interactive.

The students will demonstrate familiarity with the background research in science education by successfully producing a review of the literature (chapter II of the thesis). The second part of the two-course sequence involves the completion by each student of the research project begun in the previous course, related to teaching science at intermediate and secondary school levels. The students will develop curriculum and instructional practices using the exhibit halls, the Museum library, the private collections, and Museum expeditions (an area where the Museum has expressed interest in increasing the participation and involvement of science teachers).

### **Benefits of Utilizing the Museum as a Resource in Thesis Design**

- The students enjoy considerable flexibility in their research design since the number of resources is indeed large and varied.
- The addition of new exhibits provides the means to remain current in their chosen field of research.
- The opportunities for fieldwork that involves empirical observations are vastly superior to what they can do in the traditional setting. This greatly helps the individual to become a representative of the scientific community in the classroom, as called for by the standards.
- The opportunities to engage in expeditions will stimulate the intellectual and exploratory tendencies of the candidates.
- The use of the Museum as a teaching resource will enhance its relevance to the public as a tool for active learning rather than as a repository for human knowledge.

### **Conclusion**

There are many partnerships between museums and other institutions, such as the Institute of Museum and Library Services [3]. Some have been developed to introduce contemporary art and multicultural education into high school curricula, while others, like the New Museum [4], are designed to integrate contemporary art into curricula for English, science, social studies, and other disciplines. Unlike most of the collaborations that exist between museums and schools [5], the innovative aspect of the CUNY-AMNH program is that it incorporates the Museum into a science teacher preparation program. Similar approaches have been recently implemented through a partnership of the Virginia Collaborative for Excellence in the Preparation of Teachers and the Science Museum of Virginia, resulting in a course entitled, *Experiencing Science* [6]. These courses are examples of what can be accomplished by such partnerships. We hope that with this initiative, the goal of reaching more students and thus enabling them to become scientifically literate can be more realistically attained. At the same time, the University and the Museum can expand their service to the student population in New York City.

The author wishes to express his gratitude to Dr. Maritza MacDonald, Education Coordinator at the American Museum of Natural History, and Mr. John Nassivera from the Board of Education for their active roles in the development of this collaborative. ■

## Bio

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## USING TECHNOLOGY TO ENHANCE PRE-SERVICE TEACHER PREPARATION

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Use of the internet to deliver a portion of the content in an introductory science, education, and technology methods course for pre-service teachers provides an opportunity for a much needed introduction to basic computer literacy. A web page was developed for use in conjunction with the math, science, and technology educational methods courses at Brooklyn College. Students are introduced to this page as a group in the computer lab, and work in small groups with more experienced students serving as mentors to other students.

The Brooklyn College Science Education Webpage is designed as a simple jump page with links to various resources for science education. It serves as a starting point to expose pre-service teachers to a wide range of resources available to them on the world wide web and in the real world. Students use their internet research skills in open-ended assignments throughout the semester. The web page continues to serve as a resource for students in the next courses in the math and science education sequence. The Brooklyn College Science Education Webpage helps education graduates to begin their teaching better prepared to use technology in the classroom.

Preparing pre-service teachers to teach to the new *National Science Education Standards* [1] and the New York State *Mathematics, Science, and Technology Standards* [2] presents a challenge in science education methods classes. There is so much to cover given the scope of the elementary mathematics, science, and technology curriculum [3]. Pre-service teachers need to become competent in the breadth of science content and become familiar with pedagogical methods. Adults, like children, learn best when given the opportunity to construct their knowledge from their own experience [4]. *Science for All Americans* [5] asserts that it is just as important to consider how subjects are taught as what subjects are taught. According to Goroff, when preparing teachers, how we teach is what we teach [6]. Teacher educators must provide opportunities for pre-service teachers to do science and to use technology; not merely, provide lectures and readings about what

constitutes best practice in elementary science teaching methods. Pre-service teachers need to become informed about the standards in a standards-based learning environment.

One approach to providing an active learning experience in math, science, and technology is to introduce students to relevant teacher resources, including the state and national standards, via the internet. In this way, basic computer literacy skills are developed at the same time that science content knowledge and pedagogical issues are explored. According to the National Science Teachers' Association, "Computers have become an essential classroom tool for the acquisition, analysis, presentation, and communication of data in ways which allow students to become more active participants in research and learning." [7] A recent initiative by former New York City Schools' Chancellor Rudy Crew will place a computer in every New York City public school classroom. Instilling computer literacy that is relevant to the professional practice of teaching is essential to prepare teachers who will consider computer use to be integral to their teaching.

Introduction to the use of computers in a classroom setting is especially important for the student body at Brooklyn College. The City University of New York, of which Brooklyn College is part, has been committed to providing access to higher education for students previously underrepresented in post-secondary institutions [8]. Students in our pre-service teacher education program reflect the racially, ethnically, and socio-economically diverse urban population of Brooklyn, New York [9]. Many of our students were born outside of the United States and may be the first in their families to attend college. Most attended public schools. Kozol describes the dismal conditions often found in New York City public schools in poorer districts [10]. A high proportion report that they have not had access to up-to-date computers in high school and that they do not currently have access to computers at home. So although most pre-service education students had limited access to computers as elementary and secondary students, they are likely, as beginning teachers, to enter a classroom that has at least one networked computer. A survey of New York City teachers has found that more than half report being either poorly or not at all prepared to use technology to increase student interest or support research (i.e. access the internet) [11]. Use of the internet to deliver a portion of the content in an introductory science, education, and technology methods course for pre-service teachers provides an opportunity for a much-needed introduction to basic computer literacy.

An additional benefit of using the internet to access resources is that valuable resources can be made available to students at no cost. This is especially important for urban students who often face considerable financial hardship while attending college, and for urban teachers who will receive lower salaries and fewer resources to support their classrooms than their suburban counterparts [10].

A web page was developed specifically for use in conjunction with the math, science, and technology educational methods courses at Brooklyn College [12]. Students are introduced to this page as a group in the computer lab. Although each student has their own computer to work on, students work clustered in small groups with more experienced students serving as mentors to students unfamiliar with the internet. After a quick introduction to internet navigation basics, students surf the internet on their own starting from the Brooklyn College Science Education Webpage. The initial assignment is open-ended: to follow links to state and national math, science, and technology teaching standards; find a math, science, or technology lesson plan; and, explore two field trip sites. This collegial work on the computer builds community in the classroom [13]. The instructor is not the center of learning. The professor is present to answer questions and provide assistance. Informal exchanges between students occur throughout the session. Experienced and inexperienced students progress at their own pace. Each student comes away with increased computer literacy and an introduction to teacher resources for science education on the internet.

Students were asked to comment anonymously on their feelings about the introductory internet class session in order to plan future sessions that would better meet student needs. Student response was uniformly positive regardless of level of computer confidence and experience. One student commented, "I thought this session was very helpful. I always wanted to know more ways to find out information for teaching on the internet, and I usually come up with nothing. Now I will have more ways to find out about lesson plans, field trips, and much more to help me in my teaching." Another student commented, "The education links we were opened up to were wonderful guides for later projects. This is the first useful computer session I have attended for a class here at Brooklyn College." Still another said, "Today's class was a worthwhile break from a regular lecture class. I personally spend a lot of time on the internet and I find it extremely useful. The class web page is full of information and I will visit it often!!" A less computer-literate student commented, "I thought that this exercise was a good

experience for me because I am not comfortable using computers and I saw some great ideas for field trips, and lessons.... I will further use these sites at home to get more info to bring to my classroom.” Another observed, “I had a good time today working on the computers. I enjoyed searching for field trip ideas. We got a good sense of how to search the web and explore a particular site.”

The Brooklyn College Science Education Webpage is designed as a simple jump page with links to various resources for science education, such as the Project 2061 *Benchmarks for Science Literacy*, the *National Science Education Standards* [14], and the New York State *Mathematics, Science, and Technology Standards* [15], the full texts of which can be accessed online. These are recommended texts for this class. After our first online class, one student observed, “It helped me get a better idea of what is expected in a science classroom.”

The Brooklyn College Science Education Webpage also provides links to sources for exemplary science curriculum materials, online sources for hands-on science materials, online magazines in science, nature, and science education for teachers and children, and other useful resources to enhance science learning. It has links to ongoing research projects such as Project Pigeon Watch [16] and Monarch Watch [17] that introduce pre-service teachers to standards-based science inquiry conducted by elementary school children nationwide. Links to online magazines provide access to new sources for enhancing science literacy and awareness of the changing nature of scientific understanding. The Brooklyn College Science Education Webpage serves as a starting point to expose pre-service teachers to a wide range of resources available to them on the world wide web and in the real world.

For instance, the internet can be used to explore field trip options with great efficiency. Experiences in museums help to enrich science learning by providing informal learning experiences that are unique to the museum environment [18]. Schools and museums nationwide have entered into a partnership to improve education [19], but teachers need to be aware of the value and accessibility of these resources. Despite growing up in New York City, one of the major cultural centers of the world, most Brooklyn College students are unfamiliar with the cultural resources surrounding them. A web page linked to the Science Education Webpage was created listing field trips for science education in the New York City area [20]. This page has links to the web sites of



more than twenty-five local science museums and other non-formal science resources, including the American Museum of Natural History [21], Liberty Science Center [22], the Brooklyn Children's Museum [23], and the New York Aquarium and Wildlife Conservation Society [24]. The virtual field trips made possible by the internet serve as an introduction to the vast array of informal resources available to science educators. Students clearly understood that this page was intended to provide information for planning actual field trips, not to take their place. One student commented that she was, "especially interested in the field trip link because it tells you what is entailed in planning a class trip." Another student commented, "I enjoyed going into the A-Z Field Trips site.... I found great trips to take students on."

Students are expected to use their internet research skills in open-ended assignments throughout the semester. One assignment asks for students to research minority or female scientists on the internet. During our first session, we discovered that 20 out of 23 students think of an older, white male with funny hair, a lab coat, and glasses when imagining a scientist. Almost half reported thinking of Albert Einstein. Students are asked to nominate a scientist for inclusion in a new class web page currently under development, featuring non-stereotypic scientists. Thus, students are asked to continue to use the computer skills developed in class and are given the opportunity to work independently as online researchers. Ultimately, they contribute to an online publication. After only one or two sessions in the computer lab, students are able to independently access information for this and other subsequent class assignments via the internet.

If the ideal of education encompasses lifelong learning as a goal for all, how much more so for teachers? According to Klor de Alva, "the concept of student and alumnus will merge. Today's highly partitioned system of education will blend increasingly into a seamless web, in which primary and secondary education; undergraduate, graduate, and professional education; on-the-job training and continuing education; and lifelong enrichment become a continuum." [25] The Brooklyn College Science Education Webpage continues to serve as a resource for students in subsequent courses in the math and science education sequence, in which students must begin teaching math and science in elementary school classrooms. In still later semesters, it is available for student teachers and ultimately, for in-service teachers. It is anticipated that it will serve as a familiar reference to help beginning teachers find resources online as they face their first stressful years of teaching. The Brooklyn College Science Education

Webpage helps education graduates begin their teaching career better prepared to use technology in the classroom. ■

## Bio

Eleanor Miele is Assistant Professor of Science Education at Brooklyn College. Current interests focus on use of technology to enhance active inquiry in science education for teachers.

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## THE USE OF PROJECT-BASED LEARNING IN A TECHNOLOGY COURSE FOR MATH AND SCIENCE TEACHERS

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In this project, pre- and in-service math and science teachers used project-based learning to learn the complex skills involved in integrating technology into math and science teaching. The teachers in the course *E36.1002: Microcomputer Applications in Math and Science Instruction* in the Department of Teaching & Learning at New York University developed a four-week curriculum that integrates math, science, and technology using a common theme chosen by the teachers. The program has received very positive feedback from all participants and may be expanded in the future. Some recommendations are provided on how field experience in teaching with technology can be integrated into math and science teacher education programs.

### Introduction

The Milken Foundation commissioned the International Society for Technology in Education [1,2] to carry out a survey entitled, "Information Technology in Teacher Education." The survey involved 416 institutions that graduate 90,000 students per year. According to the survey, over 70% of teacher education programs require students to take a three-credit course in instructional technology. However, most teacher education faculty do not believe that this is preparing teachers to effectively use technology in their classrooms. The report states that the number of instructional technology (IT) courses taken is not as important as practical, hands-on experience in the use of technology in actual teaching situations. A critical deficiency in the programs that do offer technology training is that field experiences are not provided. This project, with financial support from the New York Collaborative for Excellence in Teacher Preparation (NYCETP), has developed a model in which practical, hands-on experience in the integration of technology in math and science teaching is enmeshed with an instructional technology course for math and science teachers.

### **The Summer High School Math, Science, Technology (MST) Program**

The Summer High School Program was originally run by the Academic Computer Facility at New York University to give students experience in computer science related fields. The program was then turned over to the School of Education. The advent of the NYCETP Project provided a perfect opportunity to focus the Summer Program on Math, Science, and Technology (MST). University students who had completed and excelled in the course *E36,1002: Microcomputer Applications in Math and Science Instruction* were selected as NYCETP Teaching Scholars and then asked to develop and implement the Summer MST program.

For the past four years, the model has worked very well, and the summer MST program has been designed by NYCETP Teaching Scholars working with other pre- and in-service math and science teachers. This program is open to high school students and their teachers from New York City public schools.

The main goals of the *Microcomputer Applications in Math and Science Instruction* course are to help math and science teachers become technologically literate and to enable them to learn how to use technology to enhance their teaching. One of the course requirements is to carry out a group project, and each semester a group contributes to the design of a summer MST curriculum. The teachers are asked to design a curriculum that meets the following requirements:

- 1) Complete lesson plans need to be designed and placed on the web for a 9 am to 5 pm, 5 day per week, four-week program for a group of forty to fifty students and six to ten teachers.
- 2) The program should involve hands-on inquiry learning of math and science, with a variety of learning experiences, including field trips, and work in science labs.
- 3) High school students will learn how to use technology tools, such as word processors, spreadsheets, databases, and the web in math and science learning tasks.
- 4) Math, science, and technology should be seamlessly integrated under a common theme. Activities should include physics, chemistry, biology, earth science, and mathematics.

- 5) All activities should be linked to the relevant New York State Regents syllabi and National Science Education Standards.

### **The Course - Microcomputer Applications in Math and Science Instruction**

The teachers in the "Micro" course have a wide variety of technology skills and teaching experience when they enter the class. Some are very skillful while others have never used a mouse; some are experienced teachers while others have never set foot in a classroom. The use of projects and a web-based course allows the teachers to proceed at their own speed through the various activities, and to learn technology skills in a non-threatening environment. Project-based learning has been used at many different levels as a means of helping students acquire higher order thinking skills [3,4,5]. This paper will focus on just one of the many projects carried out by the teachers, the summer high school MST program that has been partially supported by NYCETP.

### **Designing a High School Summer Math, Science, Technology Program**

The "Micro" course, and past summer programs, are models that the teachers used to design the curriculum. Last year's course outline can be seen at the following URL: <http://www.nyu.edu/classes/murfin/index.html>. Past summer programs can be seen on the web at the following URL: <http://www.nyu.edu/education/scied/summermst/>. In most cases, the sequence of technology activities designed by the teachers for the summer MST program closely parallels the sequence of activities in the course the teachers are taking themselves. The task of creating the curriculum is a very complex one requiring not only technological skill, but also pedagogical content knowledge [6] in math and in the various sciences. In order to facilitate this, a large, heterogeneous group of pre- and in-service teachers work on the project over the course of three semesters. Each semester, the summer MST group usually consists of from 3 to 6 teachers, both pre- and in-service, math and science. The project is a cumulative one, where the group in each succeeding semester builds on the work of the previous group. The use of the web pages and a web board creates the social memory that makes this possible. The NYCETP Teaching Scholars then complete the final development of the curriculum and carry out the actual instruction.

### **Teaching Math and Science With Technology**

However, there is a world of difference in designing the program and actually teaching it to high school students. Most of the NYCETP Teaching Scholar instructors in

the summer MST program are pre-service math and science teachers. In-service teachers usually have other commitments during the summer, such as teaching summer school. Every year, a computer science student is also hired, and he or she serves as the "techie" for the team of instructors. The Teaching Scholars, who work on the curriculum and teach it, come out of the experience with very strong technology skills and a very good idea of how they can best integrate technology into their own teaching. Extensive data was collected during the 1999 summer MST program. The high school students completed a pre- and post-technology survey from online forms used to evaluate each day's activities. All of this information went directly into an online database that was accessible to all of the instructors of the summer MST program.

It is very interesting how similar the group of pre-service teachers was to the group of high school students who participated in the summer MST program. The pre-service teachers used strategies and pedagogical techniques with the high school students that were almost identical to those that were used to "teach the teachers" in the Micro class. This has very important implications for teacher educators who integrate technology into their courses.

The high school students, just like their teachers, also had very different experiences with technology and some have much stronger math and science backgrounds than others. In order to deal with this tremendous diversity in the group of high school students, a large number of instructors were provided so that students could receive individual attention. The emphasis on group work also facilitated peer tutoring [7]. In many cases, a student can get a difficult idea across to fellow students far more quickly and effectively than an adult can.

## Results

The feedback from the high school students, their teachers, and the summer MST instructors has been very positive. One concrete measure of the NYCETP Teaching Scholar instructors' success is the quality of the work created by the high school students. Each year of the summer MST program, the high school students' research projects have become more rigorous and more focused on math and science. The high school student research projects from the 1999 Summer MST program can be seen at the following URL: <http://www.nyu.edu/projects/summermst99/groupprojects/index.html>. A promising trend was noted, in that the teachers and students are now focusing more on using

technology to learn math and science rather than learning technology for its own sake. In previous summer programs, both students and instructors were initially dazzled by the power technology put at their disposal. As a result, one could observe teachers and students spending hours playing with scanned images of themselves, popular sports figures, or music personalities. There was a constant struggle by the university professor to bring the focus of the activities back to math and science. Novice users of technology tend to be overwhelmed by all the effort needed just to learn how to use the software, and the reason for learning how to use the tool, i.e., to help learn math and science, is quickly forgotten. It is essential that teachers put technology in its proper place, as a tool that is no more important than any other tool that helps students learn.

The NYCETP Teaching Scholar instructors work together as a multidisciplinary team to prepare for the lessons by dividing up the work and, in effect, teaching each other. The actual teaching takes place in a very supportive environment, a well-equipped computer lab at the university. There are a large number of other pre-service teachers in the room, along with a small number of experienced teachers from public schools who also attend the summer MST programs with groups of high school students. Each summer, the summer curriculum is put together, but it is never complete beforehand. The workload on the instructors is very demanding and the Teaching Scholar instructors experience first hand the demands placed on teachers. The instructors especially underestimate the amount of preparation needed to conduct a successful lesson. This is where the university professor plays an important role, continually making suggestions, giving feedback, and ensuring the quality of the lessons before they are taught.

One difficulty that emerged was that there is a discontinuity when different persons design and teach the curriculum. Here again, the university professor needs to provide the link between the two. The cumulative model of developing the curriculum over three semesters has weaknesses, but it does allow the pre-service teachers to tackle a large, complex project that would never be possible for one group of pre-service teachers to complete in one semester.

## **Conclusions**

The NYCETP Teaching Scholar instructors' experience in the summer MST program has been an effective introduction to the practical world of teaching with technology. Each instructor receives extensive experience in working with the whole

class and also interacting with individual students. Teaching the summer MST program results in more effective learning than designing the curriculum. Those students, the Teaching Scholars, who both taught and designed curriculum, stood out from the other instructors as a result of their exemplary work. Some of these teachers eventually became technology "experts" in their schools.

## Recommendations

Future plans include having all lesson plans entered into an online database in a common format. This will help ensure quality of the lesson designs and also make the lesson plans more accessible to other teachers. A similar summer MST program for middle school students is also being considered. Opportunities to integrate field experiences with technology into the Secondary Science Methods course are also being investigated. One means of doing this might be in the development of an after-school Math, Science, Technology program in partnership with local public schools.

In any event, it is essential that more practical field experiences in the use of technology in teaching be provided to all teachers. These field experiences must involve teaching in a math and/or science context, in order to integrate technology skills into the pedagogical content knowledge of the teachers. The teaching of general instructional technology techniques in isolation from the teachers' content areas is not recommended. It is vital that all teacher educators, regardless of subject or specialty areas, become proficient in the use of technology in teaching if these valuable skills are going to be acquired by future generations of teachers. ■

## Bio

Brian Murfin completed his Ph.D. in Science Education at Ohio State University. He is presently Assistant Professor of Science Education in the Department of Teaching & Learning, School of Education, New York University. His research interests are technology in science education.

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## REPORT ON A COURSE FOR PROSPECTIVE HIGH SCHOOL MATHEMATICS TEACHERS

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The author describes his design for a course entitled *Secondary School Mathematics from an Advanced Viewpoint*. He adds subjective comments on how his design has worked in practice.

### Introduction

The School of Education and the Department of Mathematics at Brooklyn College jointly offer a program, leading to B.A. and B.S. degrees, for students who intend to teach mathematics in secondary school. These students are required to take, as mathematics courses, three semesters of calculus and one each of linear algebra, abstract algebra, advanced calculus, foundations of geometry, an introduction to probability and statistics, a one-credit course in problem-solving, and other electives. They are also required to take *Mathematics 46*, a four-credit course entitled, *Secondary School Mathematics from an Advanced Viewpoint*.

This article concerns my experience with designing *Maths 46*, which I have now taught twice. I am grateful to members of NYCETP, especially Rosamond Welchman, for many helpful discussions.

Most of the students in *Maths 46* are seniors; they are already student-teaching in Brooklyn high schools. However, when, at the beginning of the semester, I ask my students what electives they have taken or are taking, their responses show that typically they have not studied differential equations and their use in mathematical modelling, far less partial differential equations; nor, the algebra, geometry and calculus of the complex number system; nor, the theory of eigenvalues and eigenvectors of linear transformations, and their significance in applications — to name only a few of the major areas of mathematics. In the absence of these studies, my students cannot possibly have an adequate conception of what mathematics is about or how it is used in the quantitative sciences. Moreover, if they themselves do not have an appropriately

mature appreciation of mathematics, how can they inspire their students with a genuine idea of its importance and beauty?

These observations have led me to question the appropriateness, for Brooklyn College, of the prevailing view that the principal objective of a course on secondary school mathematics from an advanced perspective should be to examine the content of high school courses from the perspective of the college curriculum. An equally important objective of such a course should be to teach some parts of the college curriculum which are particularly suited to shedding light on high school mathematics, and to which the students have not yet been exposed. The main purpose of this article is to report on what I did to balance these and other objectives.

### Objectives of the Course

This section consists of quotations (in edited form) from a handout distributed to the class at its first meeting.

In this course, I want to show you some approaches to the understanding and teaching of mathematics which I hope you will be able to use by having, in my own teaching of you, an example from which you can choose to follow or diverge; and, by using your own experience as a student to give you insight into how to help the students whom you will teach.

Ideas about curriculum, the structure of classroom space and time, and methods of assessing children's progress are changing rapidly in official circles; some of these ideas will be tried in this course. You may be expected to learn, and then teach, in ways quite different from those you are used to. Because of these innovations, as well as the usual stress and excitement that go hand-in-hand with learning, you may find yourself from time to time feeling: on the one hand, anxious, bored, confused, totally lost, inadequate, despairing, angry at me or angry at yourself; and, on the other hand, curious, enthusiastic or proud of something you've accomplished. **One objective of this course** is to give you opportunities to recognise these feelings in yourself, discuss them openly and

constructively, and then, prepare to put what you learn about yourself to the best use when you become a teacher.

### THE STRUCTURE OF MATHEMATICS

I think that there is a rough hierarchy in levels of understanding of mathematics and corresponding modes of learning, just as in the case of English and other subjects. The following table illustrates this point.

	English	Mathematics	Learning Mode
<b>Power</b> of the discipline	Prayer, poetry, legal brief, political speech	Unity of all maths, aesthetic beauty, power of the quantitative world view	Inspiration from a teacher (or book)
<b>Pleasure</b> from the discipline	Reading for fun, creative writing, and speaking	Experiments in science and probability based on maths, maths-based games, puzzles	Cooperative learning, discovery by students
<b>Competence</b> in the discipline	Understanding a lease or instruction manual, writing a résumé, correct spelling, and grammar	Arithmetic and algebraic skills, ability to convert verbal situations into maths problems	Constant practice/drill

I hope that in this course you will have experience of all three levels of learning/understanding maths, and of going back and forth between them. Drill is necessary to become competent enough to enjoy the pleasurable part of maths and to appreciate its power. Having an overview of maths gives you guidance in selecting drill and experiments/games so as best to direct children towards future goals.

### The Design of the Course

#### (1) Mathematical Content

I divided the course into four modules: (a) differential equations; (b) the algebra and geometry of the complex number system; (c) the classification of congruences of the Euclidean plane; and, (d) an introduction to *Mathematica*. In choosing these topics, and in selecting the material to be presented in each, I was guided by the pedagogical

objectives mentioned above. I wanted to be able to show my students that more advanced mathematics evolves from high school maths; or, to put it another way, that high school mathematics can be presented so as to foreshadow more advanced maths. I also wanted to show them what too often fails to become apparent from an undergraduate education: that all branches of mathematics are interconnected.

For example, we can use *Mathematica* to illustrate the multiplication of complex numbers. This prepares the way for showing that complex multiplication can be performed geometrically using similar triangles. At a more advanced level, a complex-linear mapping  $f(z)=az+b$ , where  $a$ ,  $b$ , and  $z$  are complex numbers and  $a \neq 0$ , is a Euclidean congruence, consisting of a rotation about  $0$  through angle  $\arg(a)$  followed by a translation by  $b$ ; we can use either algebra or geometry to show that  $f$  is a pure rotation through  $\arg(a)$  about some other point.

As another example, in the module on differential equations, I treated the equations  $x''=0$ ,  $x'=kx$  and  $x'=kx(a-x)$ . I also covered the corresponding difference equations. I like to do this because difference equations can be treated at several levels of school mathematics. They can be solved numerically. The calculation can be automated on a programmable calculator — or, in *Maths 46*, using *Mathematica*. Difference equations also lead to solutions using arithmetic and geometric sequences and their sums. *Mathematica* can also solve the logistic difference equation, leaving us the simpler task of verifying that its solution is correct.

In general, the students used *Mathematica* to enhance their solutions of problems in the differential equations and complex number modules; for example, by plotting together the vector field and a few solutions of a first-order differential equation.

## (2) Teaching style

I had the students (I had fourteen the first time I taught the course, seven the second) form themselves into groups of three or four for the duration of the semester. Some of the material was presented in lecture format, some as projects to be carried out by the students in groups, and some in a mixture of lecture and group work.

The module on the arithmetic and geometry of complex numbers was presented in the form of problem-sets for the students to work on in groups. The problem-sets included a small amount of instructional material. The problems ranged from straightforward calculations to propositions to prove based on the results of those calculations. The intention was for the students to learn the mathematics involved by a process of guided discovery.

In the module on the classification of Euclidean congruences, I gave some introductory lectures on what it means to have a classification system for congruences, and on the proof that every congruence can be expressed as the composition of at most three reflections. Then, the students worked in groups on problem-sets intended to guide them to the discovery of: (a) how to perform translations, half-turns, rotations, reflections, and glide reflections; (b) how to diagnose a given congruence as one of these types; and, (c) an introduction to the group structure of the set of all congruences.

The material on complex numbers and most of the material on congruences could be presented as a process of guided discovery because the students had sufficient background in algebra and geometry to understand on their own the concepts introduced in the problem-sets. I did not use this approach to teach differential equations to these students, who had never seen them before. They all had had experience with anti-differentiation, of course; but, to go from there to the concept of what differential equations are and how they are applied is a very big leap, greater than most students can manage without active assistance from a teacher. So, I lectured on differential and difference equations. For the same reason, I also lectured on the classification of congruences and the geometry of complex-linear functions.

When *Mathematica* was to be used, the class met in the Mathematics Department's computer laboratory, where every student had a terminal with access to *Mathematica*, version 3.0. The students varied in their familiarity with working in the *Windows* environment; and so I encouraged them to ask for and receive help from each other. Of course, I also did what I could to help them straighten out their *Mathematica* notebooks.

### (3) Assessments

I assigned either homework or problem-sets with each module except the one on *Mathematica*. For each module, I chose a subset of the assignment, and required each group to submit to me their collaborative work on that subset. I told the class that each group member was responsible, if not for solving all the problems himself or herself, at least for understanding all the solutions that were submitted. All the students who worked on a paper received the same grade for that paper. My intention was to foster an uncompetitive, cooperative spirit. The students who were able to solve the problems would benefit from explaining their solutions to the other members of their groups who, in turn, would benefit from having the problems explained to them in a context where (I hoped) they would feel very free to ask questions. I also allowed groups to resubmit a paper after it had been marked, and to receive the improved grade in place of the previous one. I wanted thereby to encourage the ideas that: (a) what matters is learning the material as best possible, rather than learning what can be managed in a specified time; and, (b) that a grade is not a permanent attribute of a person.

Some of the homework required students to use *Mathematica*; sometimes, they were only encouraged to use it. I did not assign homework specifically within the module on *Mathematica*. This is because my students varied so much in their familiarity with programming, and even with the *Windows* environment (as I mentioned before) what would be a simple task for one student might be an extremely difficult one for another.

I gave a take-home midterm examination on the module on differential and difference equations. It contained the instruction that *Mathematica* must be used in some way, but I left it up to the individual student whether to do no more than graph the solution function, or to do much more. The degree to which *Mathematica* was used did not affect the grade.

The final examination was a two-hour, closed-book affair. I told the class it would consist of problems taken from a specified subset of the problems they had been assigned to submit. My idea was to reward those students who had fully participated in their groups' efforts rather than signing their names to papers without having completely understood them. *Mathematica*-related questions did not appear on the final exam.



## Evaluation/Critique of the Course

My main goals for the students in the course were achieved, in that:

- They experienced working cooperatively in groups.
- They had some experience with the process of making guided discoveries.
- They were openly and overtly invited to consider my own performance as their teacher, as a model to follow in some respects and to differ from in others.
- They experienced assessment methods other than closed-book, limited-time examinations.
- They understood that differential equations (and difference equations) are useful in mathematical modelling.
- They made acquaintance with the complex number system, and reviewed some high school algebra and geometry, and polar coordinates in that context.
- They reviewed some high school geometry in the broader context of studying the group of congruences of the Euclidean plane.

Several students have told me that they had never before been required to work in groups; that, after some initial repugnance, they had discovered the benefit and pleasure of doing so; and, that they were ready to use the same idea in their own teaching. They were animated and engaged in their group work during class time, and it was sometimes hard to get them to leave at the end of the period.

My impression is that the students learned more thoroughly from group work on projects than from the lecture-homework format. This is not surprising. In the former case, they work at a speed comfortable to themselves; in the latter, at the much faster speed comfortable to the lecturer. Moreover, the kind of material which I presented as group projects was less abstract, and therefore more accessible, than what I presented in lectures.

If I teach the course again, I shall try to find ways to reduce the amount of lecturing, without sacrificing mathematical honesty. For example, I shall not teach how to solve differential equations (separation of variables is the only method I used). Instead, I shall use *Mathematica* to discover a solution, which leaves us with the much simpler task of verifying that the solution is correct. This plan will also reinforce the idea that *Mathematica* is an ally, not just another body of material to be mastered.

I regret that the process of learning by making discoveries had to be abbreviated. The students should have worked more examples before the conjecture, to which they were supposed to be led, was introduced. But a true process of guided discovery is very time-consuming, and I felt pressure to cover more mathematical content than that method would have allowed. At least my students had some experience of the situation that they themselves will no doubt encounter as teachers, struggling against pressure of time and syllabus.

## **Assessment Methods**

### **(a) Homework**

There was a pervasive problem with assignments being turned in late — often very late. This problem is especially pernicious in the lecture-homework format, where a timely discussion of difficulties with homework serves to clarify and reinforce the lecture material. These valuable opportunities are lost if the homework is postponed.

There were several causes for the lateness of the students' papers:

(i) My attitude toward my students was one cause. I enjoyed the collegial atmosphere of a small course, in which we were all both teachers and learners, and the excitement of trying out new teaching methods. My interest in discussing, as the occasion arose, my own teaching style as exemplified in the course, and its good and bad aspects, was, I think, novel and useful to them, if only as a demonstration that these matters may be discussed openly. But it did have the drawback of tending to blur the distinction between them as students and me as teacher when it came to enforcing deadlines on assignments. My mistake was that I did not want to spoil the good mood by playing the role of the Old-Fashioned, Authoritarian Bad Guy who insisted on firm deadlines.

(ii) For the most part, I composed the assignments one whole module at a time. This led to relatively large assignments which were due relatively infrequently, say every three or four weeks. In the future, I shall break the assignments into smaller units, with one falling due every week. Also, in the lecture-homework format, I shall specify one problem near the beginning of the assignment, which I shall require the students to prepare for oral discussion by the very next class. I shall make it clear that these discussions are not counted toward the course grade, and that a student's contribution to

the discussion need consist of no more than saying where he or she got stuck on the problem.

(iii) In most of the groups, each student would take responsibility for one aspect of the work: solving the first third of the problems, or writing up the final paper from notes and drafts. If any one student delayed performing his or her part, the whole paper was delayed. In future, I shall require each group to plan to have *something* ready to turn in on the due date, which can later be updated and improved.

## Conclusion

In my view, the course *Mathematics 46* is obliged to attend to several goals, which are not entirely mutually compatible. For example, I want my students to have some personal experience of working in small groups, and of learning by guided discovery; but these modes of learning take more time than the traditional lecture format, and therefore operate counter to the objective of covering essential mathematical content. For another example, there is a tension between teaching that is directed to short-term needs of student teachers in their classrooms, and teaching that is directed toward providing a long-range perspective on mathematics.

It seems to me that in any undergraduate program directed toward training future high school mathematics teachers, there should be a course that fills a niche similar to that of *Mathematics 46*; and, that any such course will have to be designed as a compromise between various conflicting objectives similar to those I have mentioned. One major difficulty in designing such a course would be avoided if the mathematics electives offered to or required of these students gave them an adequate overview of what the mathematical enterprise is about. Then the necessity — which I, at any rate, felt — of incorporating a relatively broad advanced mathematical content into this course would be obviated, and one could focus more on pedagogical matters and an overview of high school mathematics.

My purpose in writing this paper has been to raise some issues which, I think, must be taken into account when designing a course along the lines of *Mathematics 46*. I also hope that reporting on my own experience with designing and teaching the course will be of use to anyone preparing to teach a similar course. ■

**BIO**

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## THE WRITE APPROACH TO MATHEMATICS OR HOW I FOUND THE MIDDLE WAY

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Revising a course is a multifaceted process. Often, reform efforts are focused on a particular aspect, that of inquiry-based collaborative learning. This article discusses the implementation of another aspect of the reform of a course for pre-service elementary teachers: the use of journals and writing exercises for evaluation and assessment. The evolution of this particular reform is traced, with emphasis on the reactions of students and faculty, the issues raised by these reactions, and the solution and resolution attained by the author is outlined.

Redesigning a course in one department that is primarily to serve the students of another department, and in fact a department housed in a separate School, is a delicate process. Sometimes, it seems the two departments in question, Education and Mathematics, do not even speak the same language. As a twenty-five year veteran of the Department of Mathematics, I thus felt some apprehension when the New York Collaborative for Excellence in Teacher Preparation (NYCETP) asked me to revise *Math 185*, the single college-level, mathematics course for pre-service elementary school teachers. Historically, *Math 185* had been used not only to provide pre-service teachers with a deeper understanding of mathematics, but also to satisfy part of the science core requirement for non-science students. Thus, some of the mathematics in the course was neither geared toward the needs of the education students, nor structured to conform to the Standards of the National Council of Teachers of Mathematics (NCTM) or the New York State Department of Education Standards. I began the planning process by reviewing these standards. The NCTM [1] quite reasonably listed problem solving as the very first standard and very few in the mathematics community would argue with that viewpoint. It was the next two standards that really resonated in my mind: mathematics as reasoning and mathematics as communication. How often have mathematics teachers heard, “I know the answer,” [maybe!] “I just can’t explain how I got it.” This is indeed a serious shortcoming in a soon-to-be professional facilitator of explanations.

I began the revision cautiously, introducing student journals and some group problem solving activities and games. At first, I gave very little direction about the journals, asking students to comment on the lesson and their understanding of it. The journals were to be done at home and handed in once or twice a week, since I was ever jealous of classroom time. I told the students not to censor their comments, but I needn't have worried — they were candid, often painfully (my pain!) so. However, I found that the journals were too unfocused and too often, time-stressed students made a brief entry that showed very little thought. I started to use more direct questions, asking them to describe specifically what they had learned, what had confused them, how had they overcome the confusion, and what they had liked or disliked about the topic. I wrote comments in the journals in response to their entries, sometimes briefly, and sometimes more at length, always trying to keep my responses positive and encouraging. When faced with an egregious error or a particularly painful comment, my response would be noncommittal, a gentle correction or perhaps an 'OUCH!'

The issue of when and what corrections to make in a journal is an important one. I agree wholeheartedly with Countryman [2] that one must primarily respond to content rather than mechanics, since the act of writing is primarily a communication between student and teacher. However, I did not take the 'freewriting' approach to journals that she suggests. She recommends having students write rapidly for a short time in class. Since I wanted more crafted answers, I asked the students to write their journals outside of class and present a polished, finished product. I did tell the students I would be happy to read anything they wrote and that they would not be graded on their spelling and grammar. However, I corrected these types of mistakes, with particularly glaring errors receiving an 'OUCH.' In the same vein, when they wandered too far afield in their journals, I tried not to judge them, but to gently bring their minds back to the task at hand. Or when necessary, I told them, "You need to put more thought into your journal entries." However, I believe it is very important in *this kind* of personal writing not to make the student feel judged or defensive. Conversely, any time student work is collected and corrected, there is another issue that rears its unsightly head: the question of grading. Because of the considerations mentioned above, I decided not to grade the journals conventionally, but to use a check mark,  $\checkmark$ , to indicate that the journal was 'acceptable.' If the student had done outstanding work in some way, either insightful ideas or excellent writing, I gave a grade of  $\checkmark+$ . Very rarely, if the student seemed to have given the

material almost no thought, and had been warned by “You need to put more thought...” before, I awarded a  $\sqrt{-}$ . I believe, for this type of personal, written work, that maintaining a supportive climate is crucial if you wish the students to give their full effort. In a reversal of the usual idea (the harder they think the test will be, the harder they will work for it), instead students will sometimes freeze up if they think they cannot perform at a satisfactory level. Tobias [3] notes that students’ passivity often results from their fears of making mistakes. In her seminal work on math anxiety, she catalogs the nature of the terrain, describing a number of issues that clearly emerged as I read the journals.

The first problem that I observed was an issue of language itself. Mathematics prides itself on its precision. Mathematical words and symbols are to have but one meaning. However we, as professionals, often do not realize that for the students, there is an ambiguity inherent in the fact that we use common English words to describe precise mathematical concepts. Is zero nothing, a place-holder, or just another ‘regular’ number; and if so, why can’t we divide by it? Pimm [4] explores the linguistic and conceptual difficulties that students encounter during the translation between the languages of mathematics and those of the classroom. Suffice it to say that the journals helped me in my exploration of this important problem. I began to realize that for some of my students solving the problem might not have been the main difficulty; the trouble may have lain in the decoding of the words of the mathematics. Thus, not only did my running dialogues with students help me provide clarifications for them, but it helped me to learn what misconceptions these, and certainly past generations of my students, held. The journals furnished me, the instructor, with enormous insight into my students’ mathematical mindscape.

There is yet another issue that the journals helped me to confront. The difficulty is by no means limited to our school, but is more severe because of our particular student population. City College is part of an urban university in New York City. The College’s original mandate was to provide an education to the children of the poor and working class people and to open to all new immigrants the opportunities of America. The campus is located in a section of Manhattan with large minority and new immigrant populations. Many of our students do not have English as their native language. Of course, there are programs within the College that address these deficiencies, but it became clear to me, as I read the student journals, that even students who had passed ESL

and writing courses had not yet achieved what I felt to be an adequate mastery of the language. I had *not* been mistaken in feeling the necessity of a strong writing component in my reformation. Once again, it was clear to me that the understanding of a procedure without the ability to clearly explain it was close to useless for a prospective teacher.

However, as I mentioned at the start of the article, I was ever aware that the course that I was modifying was a *math* course. Journals might work well in an education course, but would surely seem alien to my colleagues who would be teaching the course. One of my students approvingly characterized the journals as ‘math therapy,’ a concept that I did not think would fly with the rest of my department. In addition, I was becoming dissatisfied with the lack of focus in many of the journals. I needed to know how well students understood concepts, but too often, well-meaning students did not discuss their misapprehensions. Instead, as to be expected in a population with such a high level of math anxiety, students often merely restated what we had done in class or what they had read in the textbook. I came to the realization that there were two, truly useful types of journal entries: those that revealed students’ mathematical background/outlook, and those that offered suggestions for changes in, or reactions to, the course.

The time was ripe for another revision. I created a series of fifty-three writing exercises. The first exercise was a “math autobiography” where I asked students for their history of and feelings about mathematics. The journals had not prepared me for the flood of terror and horror this series of questions elicited. As Countryman suggests [2], it certainly “brought the issues of self-esteem and confidence ...into the open, where they can be confronted.” However, *how* to confront them was not so obvious. I offered encouragement as best I could and tried to keep the lines of communication open. In the felicitous cases, this communication offered both of us an opportunity to observe their growth. One eloquent student, who entitled her autobiography “Math Virgin,” began the course by saying, “I have only a few memories of my early math experiences and they’re all bad.” Through the semester, I watched her abilities and confidence grow, until by the end she was using words like ‘fun,’ ‘exciting,’ and ‘stimulating’ as modifiers for mathematics. As I implied earlier, the journals were not only useful as a window into the students’ minds, but as sources of comments and critiques on the course itself. They helped me clarify material and activities that had appeared muddled or unfocused to the



student. So the last writing exercise also maintained the journal format for what I called a ‘final journal entry.’ In it, the students were to discuss their reactions to the course. They were to tell what they had gained from the writing exercises and activities, what they had enjoyed, and how they would change the course, with a strong admonition to BE HONEST. THEY WERE! Before I discuss the reactions to the other revisions I made in the course, this new series of writing exercises, and a set of activities I created, it seems appropriate to describe the final revisions themselves.

In the eventual course description prepared for NYCETP, *Math 185* remains fairly conventional in terms of topics taught, and indeed no particular approach is mandated in many of the lessons. However, there is a lot of opportunity for extra problem solving (which is the *first* NCTM Standard [1]) and collaborative work built into the course. I created four, full-period activities, one on each of the four major topics in the course. They are to be done by students using manipulative materials in a math resource room. (My difficult, but successful battle for the creation of such a collaborative learning center, ‘owned’ by Mathematics, is yet another story.) Additionally, I created/compiled twelve, brief collaborative learning exercises, consisting of more challenging problems or ‘mini-activities,’ which required no manipulatives and could be done in a regular classroom on a weekly basis. In the new, improved writing component, besides the autobiography and course summation, students were required, every week, to submit relatively brief answers to four or five ‘thought’ questions: either, challenging problems, explanations, or analysis of fictitious students’ work; or, comments on material taken from various ‘real-life’ sources.

Now we come full circle to my opening remark. Importation of educational reform into a course, which has been ‘conventionally’ taught since time immemorial by a species of department resistant to what it views as flighty fads, is tough. Now, before a posse of mathematicians saddles up to bring me to justice, let me clarify my remarks. I am not a whole-hearted constructivist. I believe there is a place for lecture in the classroom. I admit to a hankering for a tee shirt that says, “...because I’m the teacher.” However, I do believe that, unless we get our students to be more actively involved in and to take more responsibility for, their own learning, ...well, we can all finish that sentence. So how was I to effectively preach my middle way?

The activities were the easy part. After piloting them in my own classes, I offered to run them with colleagues also teaching the course. I invited faculty to attend these jointly run sessions via notes, fax, email, and unashamed begging. Clever notices piqued curiosity. (“Don’t miss a chance to obtain tickets hotter than those for the new Rolling Stones’ concerts. And Dave and I are younger [not by much!] than Mick.”) About fifteen members of the Mathematics Department came to observe the activities and the responses were almost universally positive. One senior member of the Department commented, “What I saw deserved videotaping...terrific interaction, exploration.” The chairman mandated that the activities were to be an official part of the course. The inclusion was especially easy, since by then we had the resource room with a file drawer containing the materials for each activity. I met with instructors each term to go over the activities and am in the process of writing up a cover sheet for each investigation for the faculty members teaching the course. I think I’ve clinched the sale.

The students were even easier to convince. They fairly uniformly adored the activities from the start. An “A” student who began the course saying (in answer to a question from the autobiography) that she was too busy to work with other students and found group work to be a waste of time, ended by noting that she found the activities “challenging and intriguing...[they] made the concepts much clearer.” Even a failing student, who felt the course was unfair and demanded too much work, relented by saying, “I really enjoyed the activities.” The universal cry, especially from the weaker students, was, “More activities!” Now some of this may be ascribed to the fact that there was a strong ‘game’ flavor to the activities. Furthermore, students enjoyed the interaction with classmates, often finding the act of explanation to be empowering. To wit, “Today I suggested to Geraldo that there was more than one answer and *I proved it to him!*” Many of them echoed the student who, in referring to using colored chips to represent signed numbers said, “I wish my teacher in junior high school had known about this.” Students that were already in classrooms with children brought some of the material I gave them to those classrooms. One student, thrilled by the reaction of her class to a challenging problem, said, “I just love it when the children get into a heated discussion about math.” Amen!

One full-period activity is to be done as an introduction to number bases and a review of positional notation. The students earn and spend ‘money’ in fictional countries

with base six and four currencies. Of course, the words “number base” are not used. They use the ‘money’ in various situations and then answer a series of questions designed to lead them to a deeper understanding of arithmetic operations in our positional numeration system. Student responses to this activity were almost invariably positive. One woman said that she finally truly understood what ‘carrying’ in addition meant. Another rejoiced that, “I [now] view math as part of life.” A mother remarked that she had begun playing the game at home with her children. My favorite comment was, “[the activity was] a game in which you never lose because you are learning and having fun at the same time.”

To be fair, the response was not 100% positive. One foreign student felt uncomfortable with the interactions within his group, feeling that his classmates were not serious or respectful enough. Another thoughtful student felt that the activities provided some interesting facts, but did not allow enough time to “learn to apply the formulas to various types of problems that might arise.” She felt that they sometimes “took time from the lesson which could have been spent preparing for the topic.” I’m sure many math faculty would agree with her, as perhaps even I would, but the activities did not absorb the bulk of the semester. I mostly taught by ‘imparting knowledge,’ keeping the students active by having them present problems and calling on them for answers during class.

What of the new writing exercises? Of course, *I* felt that they were a great success. I was able to continue the dialogue with the students and I tried to keep my comments as encouraging as I could. I was able to become even clearer about their misunderstandings and direct them to the kind of material they needed to study and urge students to see me to talk about the ideas. The applications drawn from newspapers or classroom scenarios made the fourth NCTM Standard, making connections, come alive. All the difficulties in using mathematical language and the confusion of mathematical terms with those same words in natural language, as discussed above, were even more clear than they had been with the journals. I also could see the clarification process, as when students, who could not distinguish between the concepts of factor and multiple, were able to do so after an activity that focused on these concepts. It certainly was work to correct and comment on the writing exercises, to give hints and encouragement on the problems, but I felt that I was amply repaid by the learning that I saw occurring. Also,

some of my best students were lavish in their praise of the use of the writing exercises, saying, "I would feel much more comfortable [at the end of the semester] if I ever were to have to explain [math] in words." Another rhapsodized about "how wonderful it is to speak in numbers and words." Many asserted that the writing exercises had helped them to get a better understanding of the topics. However, only a minority unreservedly approved of the required writing, and they were the people in the class who felt comfortable with the process of expressing themselves. The majority of the students did not really like this type of assignment. They found it "hard," "vague," "mind-wrenching," "way too much," and "too demanding," to quote a few negative comments. Even when they admitted it was 'good' for them, they likened it to a dose of castor oil. They told me it was too time-consuming and they resented it being given in addition to conventional homework. Suddenly the writing had gone, for some, from being 'math therapy' to 'math punishment.'

It was clear to me that there were two major components in this unfortunate transformation. The first hinges on the answer students gave to the question, "Are you busy?" in their autobiography. Most said numerous obligations and responsibilities filled their lives. The vast majority had jobs, some full-time, as well as families that included one or more children. Many of the women headed single-parent households. Others said that they were taking a large number of credits that semester because they needed to finish their degrees quickly. Their final summations revealed that they found that the course demanded too much of their time. The new writing required much more time and effort than the journal entries I had required in the past. The second, related issue is a fact just glancingly mentioned in the first paragraph of this paper. *Math 185* was, until very recently, the *single* college-level course required of pre-service teachers, with a prerequisite of only about 1½ years of high school mathematics. The reformed course, with its increased emphasis on the importance of explanations and higher order thinking, demanded a stronger background than this requirement. Through my unrelenting nagging and the intercession of the New York State Education Department, the College has now strongly recommended the adoption of a new prerequisite for *Math 185*: a NYCETP-developed Quantitative Reasoning course. I am confident that as the students enter *Math 185* strengthened by this new requirement, they will find the demands of the course to be more reasonable.

There remains one other, dirty little reason that the students do not extol the virtues of the course writing requirement. I grade it. I use a scale of 1 to 10, rarely giving a grade below 6 to a serious effort. I tell them I will drop the lowest three grades and count the average of the remaining exercises as one test. Generally, this score helps most students' averages, but they don't like being graded. How did such an initially empowering activity come to such a sorry pass? I started grading for two reasons. I felt the need for alternative assessments and the writing provided an excellent vehicle for evaluating creative or reflective approaches to addressing problems. Open-ended problems, questions on each of the four activities (horrifying for those students who enjoyed the activities, but not these questions), discussions of communication issues, and analyses of complex situations are all forms of alternative assessment. I use these along with quizzes and class participation to augment the grades from class tests and the final. (See Kulm [5] for an excellent discussion of assessment options.) But it is amazing how appealing rote recall of algorithms can appear when compared to being asked to provide cogent, well-phrased answers and explanations.

Finally, what about my colleagues? Well, they hate the idea of the writing exercises almost as much as my students. Reading such material in the context of a math class seems to feel no more natural to most people than writing it. However, I have acquired a powerful ally. The New York State Education Department has strongly encouraged 'writing across the curriculum' in liberal arts classes for education students. The new state licensure exams, including the parts that test mathematics, require that students exhibit proficiency in reading and writing. I will continue to refine the writing exercises, hone the activities, and lecture when I see fit. My strongest students offer me support in my own middle path between the needs and demands of mathematics and those of education. A student, who began the course fearful of mathematics and achieved a grade of "A," comments on a strongly constructivist methods course in which she was enrolled concurrently with my course. "I like the hands-on approach to teaching, but it moves too slowly for me. [Also,] I have a yearning to conquer my fear of 'traditional' math. I need to be challenged and I want to learn some of the 'deeper' concepts that I could never grasp. I find the mixture [of approaches] to be the most stimulating." Viva language and the 'middle way!' ■

**Bio**

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## **PORTFOLIOS AND PERFORMANCE ASSESSMENT: TOOLS FOR CHANGING PEDAGOGY WITH PRE-SERVICE MATHEMATICS TEACHERS**

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Portfolios serve many roles in the development of prospective teachers. Faculty at Brooklyn College found that portfolios can play two other important roles — as tools in faculty development and as a conduit in the development and description of college curriculum. Faculty came together to design a portfolio outline which both defined the introductory mathematics methods course and facilitated establishment of standards. The format was adapted for other populations, each time being modified to suit the new context.

Teacher preparation programs are paying increased attention to the role of portfolios in their curriculum, as many schools are exploring use of portfolios with children, and some states are requiring teaching portfolios for certification. Meyer and Tusin distinguish between the prospective teachers' perceptions of portfolios as "process" or "product" [1]. Corresponding to this distinction, two primary roles that portfolios play in teacher preparation are to further the teachers' personal growth [2,3] and to evaluate the teachers [4]. These two roles are not independent, as indicated in the Assessment Standards for School Mathematics proposed by National Council of Teachers of Mathematics (NCTM) [5] which include as one of the six standards the "Learning Standard;" namely, that "Assessment should enhance mathematics learning." It is also appropriate for prospective teachers to experience development of their own portfolios as a model for how children might engage in the same process [6].

Faculty at Brooklyn College have found that portfolios can play two other important roles — as conduits for increased faculty communication, and as a means of describing the key themes and expectations of a course or program.

### **The Introductory Mathematics Methods Course for Elementary School Teachers**

Each semester at Brooklyn College, over two hundred students are enrolled in about eight education courses concerning methods of teaching elementary school mathematics.

These students are drawn from three different populations: undergraduate daytime prospective teachers; undergraduate students who are taking the same courses at night, often because they work as paraprofessionals; and, post-baccalaureate but pre-graduate elementary teachers. Over the years, a number of innovations have been introduced that have benefitted both students and professors in all of these courses, including: (1) diagnostic pre-tests; (2) the use of hands-on activities and manipulatives which enhance students' understanding of basic concepts and offer a base from which to build understanding of others' knowledge in mathematics; (3) the modeling of multiple types of assessment. A number of faculty had tried some form of portfolio assessment, but these portfolios often lacked clear definition, and the result was that at the end of the semester, the Mathematics Education faculty could barely be seen behind stacks of bulging looseleaves, boxes, and bags. Burn-out was imminent.

The large number of courses, taught by at least eight different full- and part-time faculty members, has raised issues: how to define course content and ensure coverage of this basic content for this diverse population; how to promote a conversation among the richly varied teaching staff (full-time faculty, and school personnel with varied backgrounds); and, how to model new forms of assessment in a practical way. With the formation of the New York Collaborative for Excellence in Teacher Preparation (NYCETP) came the opportunity to tackle the third issue of assessment, which also served to address the first two issues.

A committee of full-time and adjunct faculty met over several semesters to develop and test a portfolio requirement which would be suitable as part of the assessment for a range of courses. Portfolios also gave the faculty the opportunity to focus not only on the traditional elements of teacher preparation, such as planning and reflective practice, but also on new areas, such as standards, mathematical thinking, writing, and furthering one's own mathematical learning. The work of the Portfolio Committee was grounded in the realities of urban schools and fueled by the contexts of various school reform efforts in New York City through the input of adjunct faculty, most of whom are school practitioners and work daily as staff developers, district coordinators, and school leaders in mathematics.

After a number of semesters of designing and implementing various pieces of the portfolio, the team was satisfied with six sections as being representative of what all of



the introductory K-6 mathematics methods courses should highlight. Colored cover sheets were duplicated for every student in these programs. Each page had a brief rationale for inclusion of the section, followed by guidelines and some examples of what might be included. Students were asked to include material satisfying the guidelines which represented their best work and to explain why they submitted these items. The full page is included for section six below. Others have similar elaborations.

### **Section 1: Design of Mathematics Material and Planning for Its Use**

### **Section 2: Selection and Use of Commercial Mathematics Material**

### **Section 3: Assessment of Individual Children's Mathematical Thinking**

### **Section 4: Integration of Mathematics with Other Curriculum Areas**

### **Section 5: Reflection on Teaching Practice**

### **Section 6: Lesson Planning – Teaching Mathematics to Small Groups**

Careful planning is essential if a teacher is to maximize children's learning in the relatively short time available to devote to mathematical ideas.

This semester, you have been writing lesson plans according to a format which asks you to write extensively about key elements of a lesson. In the next pages, include a lesson plan which you have executed, together with your critique of the lesson, and samples of student work.

Below, discuss why you chose this lesson to include in your portfolio. Also, discuss whether (and how) it could be adapted for other instructional settings — for example, whole class vs. small group, a different grade level, or a different mathematical skill.

Throughout the semester, class activities, field assignments, and other work culminated in discussions about selecting work to include in portfolios. These discussions invariably included a focus on standards, demonstrating *emerging knowledge* of mathematics pedagogy and deepening understanding of mathematics. The final result

became a manageable and focused selection of student work. As portfolios were completed over successive semesters, exemplary student work was collected to be shown to later classes. When students see models of superior work, the overall level of portfolio entries is raised.

As a result of use of this portfolio model over three semesters, faculty began giving a more uniform range of assignments, and also grading patterns became more uniform among different sections of the same course. Students could see the commonality of courses throughout the program, rather than reflecting individual characteristics of professors. Students reported that their preparation of a mathematics education portfolio was very helpful as an exhibit in job interviews.

### **Adaptations for Other Contexts**

The work on portfolios at Brooklyn College went well beyond the initial preparation of elementary teachers. Professors in both middle and secondary mathematics education began to use the same approach with graduate program and in-service courses. In each new context, the model was modified and enriched. Portfolios became a way of defining program objectives and standards.

**A. *Elementary Masters program:*** Teachers enrolled in a masters program, with a specialty in teaching mathematics in grades K to 9, take a sequence of four Education courses as a cohort. Currently, the cohort numbers nearly 50 per year. These teachers are already provisionally certified, and should all have had a course such as the one described above for which the portfolio was designed. For the sequence of four courses, the faculty agreed that each semester the students should be able to add materials relevant to that course to a section in each of four broad categories: Looking at Curriculum, Looking at Children, Looking at Policy, and Looking at Connections. In each course, all assignments could be included in one of these sections. For example, in the first course in this sequence, written assignments were given throughout the course, from which one or two examples could be selected or modified and submitted. Examples for each category were: analysis of how texts or other curriculum materials match the New York State Curriculum Standards; case studies of children's understanding of particular concepts; description of and rationale for exemplary practice in early childhood mathematics; and, identifying mathematics potential in science museums and designing a "Treasure Hunt" for students to use there, as they develop or apply mathematics topics or

processes that they are learning in school. The portfolios assembled by the teachers in the first course were passed on to the professors in the next course, as a way to introduce the teachers to their professors through their work. Portfolios used in this way promoted better articulation among the courses in the sequence. They also made it easy for faculty to consult with each other about grading practices.

***B. Secondary undergraduate methods course.*** The faculty for the student teaching seminar in secondary mathematics began with the same general portfolio outline, but used this framework to have students develop a holistic rubric which was used to evaluate the class portfolios, using a 1-6 scale for each section. This work on developing rubrics fit in smoothly with consideration of the new performance standard recently adopted by New York City's Board of Education.

***C. Mathematics courses in Masters program.*** Portfolios had played a role for several years in a geometry course for teachers of grades K to 9. This course exposed many teachers for the first time to the possibilities for visual creativity in geometry. When left undefined, the portfolio became a large collection of two and three dimensional constructions. A more focused portfolio was initiated in another course for the same population, Number Systems and Algebra. This portfolio had only three categories and for each, students were to select one item. They were given three cover pages to describe and organize their work. The three categories were: Exemplary Solution to a Problem, in which students were to concentrate on the generic NCTM Standards of Problem-Solving and Communication; Review of a Resource Material (intended to be non-textbook, and approved by the instructor); and, Evidence of Independent Study. The latter two categories were included in recognition of the fact that, in the current climate of reform of school mathematics, teachers are being required to learn and apply mathematics topics that are new to them. Teachers must become life-long learners, and cannot rely on all the mathematical information they need coming to them through coursework. They must learn of the many resources available through which they can learn — books, journals, web sites — and they must develop a critical approach to these resources, recognizing quality in mathematical thinking. Student portfolios which fit this structure have been useful tools in communicating to new mathematics faculty the special nature of these courses and how they promote the professional development of teachers of grades K to 9. A similar portfolio structure is being developed for the remaining four mathematics courses in this program.

***D. In-service courses.*** Faculty who had been part of the development of the initial portfolio took the same model to in-service courses, but adapted it to suit the population. For example, in a funded, in-service program for secondary teachers, all of whom are teaching a quite similar curriculum, an important component of the portfolio became the inclusion of evidence of student work. In another funded program, Mathematics Education faculty team taught with faculty from Geology and Mathematics departments. Portfolio entries had an interdisciplinary flavor in this setting. The Mathematics professor subsequently began asking students to submit portfolios of their work in a mathematics course for undergraduate prospective elementary teachers.

The use of portfolios in the mathematics education strand is now being examined by faculty in other content areas. What began as a technique for defining a particular course is becoming a technique for defining a teacher preparation program. The development of this portfolio model could not have taken place without the input of a dedicated faculty, some of whom contribute to the work at Brooklyn College in addition to their heavy responsibilities in the Board of Education. We would like to thank Josephine Urso, Trudy Adducci, Joseph Porzio, Debbie Montagna, Terry Gurl, as well as our full-time faculty, David Fuys, Livia Denis, Brenda Strassfeld and Barbara Freeouf. ■

## **Bio**

Rosamond Welchman is a professor in the School of Education at Brooklyn College of the City University of New York. After earning a Ph.D. in Mathematics, she began her teaching career in mathematics departments. She had the opportunity at Brooklyn College to begin teaching a combined mathematics, methods, and field-based course, and soon became a member of the faculty of the School of Education. She has been Program Head of the Early Childhood Division, both Acting Assistant Dean and Acting Dean of the School of Education, and is currently Program Advisor for secondary mathematics teachers. Her publications include: a mathematics/methods text for elementary teachers co-authored with David Fuys; a monograph reporting on research into the Van Hiele model of thinking of adolescents, co-authored with Dorothy Geddes and David Fuys; and, five other books for teachers with an emphasis on uses of interesting contexts and manipulatives that promote problem solving and reasoning. She has been involved in a number of funded projects for staff development in local schools, and has also been invited to teach as a visiting faculty member in Oregon, California, Texas, and Mississippi. She frequently gives workshops and other presentations for local teachers.

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# **HELPING CHANGE OF CAREER INDIVIDUALS TO PREPARE TO BECOME SECONDARY MATHEMATICS TEACHERS**

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This article describes the development and content of a special introductory course developed and offered at New York University for change of career individuals entering the field of mathematics and science teaching at the graduate rather than the undergraduate level. With a critical shortage of qualified mathematics and science teachers at the secondary level being exacerbated in urban public schools, such as those in New York City, by high attrition rates during the first few years of teaching, it is important to find and encourage new populations of potential teachers. One such population is that of career changers, and the course described in this article is an attempt to help such individuals make their career change more smoothly and successfully. The focus of this course, and the illustrations provided in this article, are on the three major themes: "What Does It Mean To Be An Effective Mathematics Teacher"; "Technology and the Internet"; and, "A Model of Effective Mathematics Teaching."

## **Introduction**

A growing body of research attests to the fact that there is a critical and continuing crisis in the lack of qualified teachers in the public schools. For example, the study *What Matters Most: Teaching for America's Future* (National Commission on Teaching and America's Future, 1996) states that over 50,000 inadequately prepared teachers enter the teaching profession each year. In particular, reports have shown that in grades 7-12 approximately 33% of mathematics teachers and 20% of science teachers do not have either a major or a minor in their field.

These shortages are even more acute in urban areas such as New York City. According to an article in the January 5, 2000 *New York Times*, the New York City Board of Education expects to have to replace 10,000 additional teachers over the next five years because of the large number of teachers who will either be retiring or moving to other, higher paying locations. This expectation exacerbates an already serious shortage of certified teachers in the New York City public schools. Further aggravating this shortage is the high rate of attrition of teachers in urban areas. According to a recent statistical

report of the United Federation of Teachers, 18.5% of new teachers in the New York City public schools do not return for their second year of teaching, 31% leave the New York City public schools by the end of their third year, and 41% leave by the end of their fifth year.

One of the consequences of this continuing shortage of qualified secondary science and mathematics teachers is that new populations of prospective teachers must be sought out and encouraged to enter the teaching profession. One such population is that of career changers, individuals who have an undergraduate degree in a field other than education and thus begin their teacher preparation at the graduate instead of the undergraduate level.

These new teachers have a very short time in which to take the appropriate education courses and be placed into a student teaching internship. Because they often have a preconceived but erroneous image of what teaching is all about and what makes an effective teacher, it is important that they be given an early overview of the field into which they are moving. This enables them to make sense of the courses in which they enroll and take the utmost advantage of the student teaching experience.

At the urging of several graduates of the Masters Degree Program in Mathematics Education at New York University who were themselves career changers, Dr. Kenneth Goldberg developed a new course in spring 1998 that would provide this important overview of and introduction to teaching during the first semester of masters degree study for change of career individuals. The course, *E12.2089: Preparing to Teach Secondary Mathematics*, is a one-point course that meets once a week in the evening for two hours, for a total of six weeks.

### **Focus of the Course**

The course *E12.2089: Preparing to Teach Secondary Mathematics* introduces change of career individuals to: an overview of current issues in mathematics education; the local, regional, and national professional mathematics education associations, and the resources and support these associations provide to new and continuing teachers; and, use of the internet in order to access useful information, resources, and communicate on a regular basis with other mathematics educators to share experiences, concerns, questions, and stories of success.



E12.2089 uses the “Starter Kit” from the National Council of Teachers of Mathematics (NCTM) as its main resource. This kit contains copies of the NCTM journal *The Mathematics Teacher*, copies of NCTM position papers and statements, and a summary of the NCTM *Standards* and its history and purpose. A secondary resource is the book entitled, *Teaching: Making Sense of An Uncertain Craft* by Joseph McDonald. In addition, articles from newspapers, journals, and the internet, as well as video tape clips, are used to generate points of discussion.

Each semester, the students in the class select a focus topic from what they have read in the newspapers, seen on television, or heard through membership in internet discussion groups. In one semester, for example, the class focused on the so-called “Mathematics Wars” taking place in California. In this debate, some parents and educators contended that current mathematics teaching and curricula was “soft” and did not focus enough on the development of important mathematical skills; while others argued that mathematics involved more than just the development of algorithmic skills and that equal, if not greater, importance needs to be put on reasoning, estimation, and problem solving. Students in the class had to read newspaper and journal articles, as well as follow the internet discussions taking place on the NCTM list serve and in internet sites, such as the Math Forum at Swarthmore College.

### **Student Involvement in Setting the Agenda for the Course**

The objectives of the course are intended to meet the needs of the students. Furthermore, since the students are all change of career individuals who have made conscious and explicit decisions to become teachers, these students usually have a sense of what they want and need to know about the new career into which they are moving. Consequently, the first class session usually consists of a group discussion culminating in a listing of the objectives of the course for that particular semester. Following, for example, is the list of objectives developed by the students who took the course in fall 1998.

Objectives: At the conclusion of this course students will understand and be familiar with:

1. New York State Certification and New York City licensing requirements

- for teachers.
2. Use of e-mail, listservs, and the internet for communication and information.
  3. Recent national history of mathematics education from the New Math, to the Back to Basics Movement, to the NCTM Standards and beyond to today's controversies.
  4. The current New York State mathematics curricula and exams, where they came from and why, and proposed future changes.
  5. Professional associations and what they provide for teachers, including the National Council of Teachers of Mathematics, the New York State Mathematics Teachers Association, and the Association for Supervision and Curriculum Development.
  6. Discussion and use of videotapes to show different teaching styles and approaches.
  7. Instructional and educational materials available to teachers.
  8. Discussions of current issues and concerns, including the NCTM *Standards*, and the latest TIMSS (Third International Math and Science Study) and NAEP (National Assessment of Educational Progress) reports.

Three of the major themes of the course are: (1) what it means to be an effective mathematics teacher; (2) the use of technology, in particular the internet, to support and enhance the teaching and learning of mathematics; and, (3) how to use a model of instruction integrating content, questioning, and assessment as the organizational framework for classroom practice.

### **What Does It Mean To Be An Effective Mathematics Teacher?**

Change of career individuals often come to teaching with a preconceived idea of what a teacher is supposed to be and what a "good" classroom should look like. It is important for them to understand that teaching is a craft that is as individual as the people who become teachers, and that a person needs to find the teaching style and persona that is appropriate and right for them. It is also important for them to realize that whether learning and understanding is taking place in a classroom is more important than how the classroom looks to an outsider. To make this point, we ask the students, as their first homework assignment, to think about their own former mathematics teachers and to imagine the kind of teacher they themselves would like to be in five or ten years. They are

then asked to write down a brief description of their future selves that they can share with their classmates as the basis of a group discussion at the next session.

These presentations lead to a spirited discussion of the characteristics of an “effective” teacher, and what a “good” classroom should look like. Some students feel that, to be an effective teacher, you must create an atmosphere of informality in which the students work together on group projects and the teacher serves as a facilitator. Other students then argue that an effective teacher is one who manages a class well and keeps the students attentive and quiet, responding only when addressed directly by the teacher.

After this discussion has gone on for a while, we watch video clips illustrating a wide variety of teaching styles which, though different in many ways, all present models of effective teaching. Through these discussions and illustrations, the students come to understand that teaching is a very individual craft; they will need to find the model and the style that will be comfortable and right for them; moreover, this is an ongoing process as they mature and develop as teachers.

### **Technology and the Internet**

One of the aspects of current teacher preparation that has the greatest potential for providing support and a wealth of invaluable resources is the internet. At the same time, the internet is a part of life that change of career individuals have not grown up with as a regular part of their lives. Consequently, an objective given high priority in this course is an introduction to the internet and its use for educators.

At the second session, all students are asked to complete materials that will be used to give them computer accounts at New York University and free, unlimited access to the University’s computer labs. A list is then passed out containing 20-25 world wide web addresses of sites related to mathematics teaching in some way. Some of these are government sites (the New York State Education Department, the New York City Board of Education, the U.S. Department of Education and the National Science Foundation); some are professional organization sites (NCTM, ASCD, the National Board for Professional Teacher Certification); some are sites where lesson plans, discussion boards, and articles on educational topics are available (The Math Forum at Swarthmore College

and the Eisenhower National Clearinghouse at Ohio State University); and, some are sites where information on various mathematical topics can be found (ERIC).

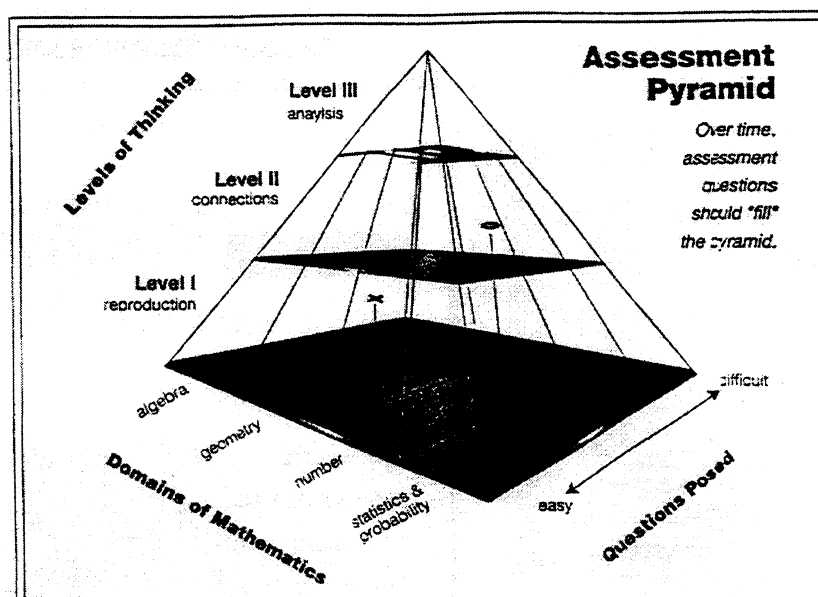
Each student in the class is randomly assigned two sites from the list. Their assignment for the next class is to visit that site by computer link and report on who hosts the site; what useful information, resources, or links the site provides; and in general, why a secondary mathematics teacher would want to be aware of this site and what educational use they can make of it. For the next class, we have a live internet hookup available in the classroom so that, as the students present their findings, they can actually show the site and its contents, illustrating how its resources may be accessed and how its links to other useful sites actually work.

By providing this introduction to the internet and its accessibility in this class, instructors in all the other courses the students take can assume internet familiarity and integrate the use of the internet into the course lessons, homework assignments, and group projects. The students also learn that the internet is an unfiltered mass of information, some of it useful and some of it not, and that they, as professional educators, need to learn to be careful and questioning consumers of what the internet has to offer.

### **A Model of Effective Mathematics Teaching**

One of the beliefs of new teachers, especially those who enter the teaching profession after a career in some other field, is that teachers just walk into a classroom and present information to the students from a textbook or a curriculum guide. They are unaware that teaching has the best chance of being successful if it is based on a model that helps the teacher plan for both short and long term learning goals in a structured fashion. And, while we want new teachers to understand that there are many different models of effective teaching available to choose from, this course provides a wonderful opportunity to expose them to one such model so that the use of such a model can be discussed, analyzed, and understood.

The model we employ in this course is one adapted from Verhage and de Lange called the “Assessment Pyramid” [1] and is shown in Figure 1 below.



The three dimensions of the pyramid model represent the content to be presented over the course of the semester, the level of difficulty of the questions the teacher poses to the students, and the level of thinking these questions require of the students. Each point within the pyramid represents a unique combination of these three components and the idea is that, over the course of the semester, the activities, assignments, and questioning should cover all levels of the three dimensions of the pyramid and thus fill in the pyramid with points.

Once this model has been introduced, discussed, and understood, we illustrate the components of the pyramid, the levels of difficulty for questions, and levels of thinking of the students by using articles from *THE MATHEMATICS TEACHER*, other journals, and video clips, depicting a variety of classroom activities. As the students take other courses in their masters degree program, they will be exposed to many other models of teaching, and will be better able to understand and evaluate these alternative models given this early introduction.

## Summary and Conclusions

The purpose of this new graduate level course was to help change of career individuals make a smoother and easier transition from their former careers into teaching. The success of this course will be measured by the percentage of students who take the course, complete their degree and certification requirements, begin their teaching careers, and continue as teachers in the New York City public schools. Since the first offering of this course was only in 1998, it is too early to tell whether or not this success will be achieved. However, since the change of career masters degree program takes two years to complete, the first cohort of students taking this new course will be graduating at the end of spring 2000, and data of the sort needed to evaluate the effectiveness of this course can begin to be collected at that time. ■

## Bio

Dr. Kenneth Goldberg is Professor of Mathematics Education and Director of the Mathematics Education Program in the Department of Teaching & Learning of the School of Education at New York University. He is a Co-Coordinator of the New York Collaborative for Excellence in Teacher Preparation (NYCETP), and the Co-Director of the Mathematics and Science Teacher Enhancement Program (MSTEP) at New York University funded by a Dwight D. Eisenhower Grant from the New York State Education Department. Dr. Goldberg is a former president of the New York State Mathematics Teachers Association. His areas of specialization are statistics and the implementation of technology as an effective method for teaching mathematics.

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## **A CASE STUDY OF AN ONLINE SCIENCE FAIR – THE INTERNATIONAL CYBERSCIENCE EXPO 2000 (ICE2000)**

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The International CyberScience Expo 2000 is a project that promotes project-based, science learning by secondary students. The event was organized and held entirely online in a collaborative virtual learning environment called ScienceMOO. It was found that ScienceMOO had great advantages and disadvantages as a tool for organizing and staging synchronous online events involving large numbers of people. Scheduling of online, synchronous meetings between the students and judges was very challenging. However, when judges did manage to meet with students, many beneficial interactions resulted.

### **Introduction**

Technology is a tool that allows one to create learning environments that are very different but in some ways quite similar to traditional learning environments. The initial idea for an online science expo arose during a conference that was sponsored by the New York Collaborative for Excellence in Teacher Preparation (NYCETP) that was held in spring 1996 at New York University. The plan was to have NYCETP Master Teachers help their students develop science research projects that would then be exhibited in the online science expo. NYCETP Teaching Scholars would work closely with the NYCETP Master Teachers to provide individual assistance to the students in getting their projects completed and on the web. The Teaching Scholars gained valuable experience in educational technology through their work facilitating individual web-based projects, and also by helping out in the administration of the online event.

The International CyberScience Expo 2000 (ICE2000) used a technology tool called a Multi User Dimension Object Oriented (MOO) to begin to examine learning that takes place during large, online, educational events, such as science fairs. The following research question was investigated: What are the advantages and disadvantages of the use of collaborative virtual learning environments for holding large online events, such as science fairs?

## **Procedure**

Over a period of two weeks in June 1999, over two hundred secondary students met with judges to discuss the students' science research projects. The students, from both middle schools and high schools, worked on their science projects in groups or individually and then placed posters explaining their projects in an assigned room. At the scheduled time and date, the judges met the students in their rooms and judged the projects. The scores were submitted, totaled, sorted, calculations made, and prizes awarded. However, there was one way in which this science fair was very different from any other science fair that occurred before it.

## **Everything took place in cyberspace!**

The main goal of The International CyberScience Expo 2000 (ICE2000) was to promote project-based, science learning. Project-based learning was chosen as a pedagogical technique in order to foster the acquisition of higher order thinking skills. Modeling [1] and interaction in a multiple electronic zone of proximal development [2] were the main mechanisms by which the students would acquire higher order thinking skills and learn science. Further particulars may be found on the ICE2000 web site at <http://www.cat.nyu.edu/ice2000>.

Secondary students and teachers from all over the world were recruited through the use of email announcements; flyers were sent to New York City public schools. These participants were physically located in many different places, including Harlem, Chinatown, Brooklyn, and even Toronto. Allowed to work in groups or individually, students' science projects can be viewed at the following web site: <http://www.cat.nyu.edu/murfin/ice2000/projecturls.html>. ICE2000 differed from other large science competitions, such as the Intel Talent Search, in that it was open to all students, not just to the top students in a school. Students who traditionally do not take part in science competitions had a chance to present their work to their peers and to scientists, and all students who completed a science research project and placed it on a web page were eligible to take part. Since there was no preliminary screening of projects, this led to a wide variety in the quality. This was a way to encourage participation by all students, regardless of ability. In the future, the standards will be raised for project entry as schools, teachers, and students gain confidence and skill at



conducting web-based science research. Feedback from the judges on projects was emailed to all participating teachers after the projects were scored and the prizes awarded.

The ICE2000 judges were recruited through the use of email invitations to major organizations for scientists such as AAAS, the New York Academy of Science, and to the email lists associated with organizations for scientists. Webmasters of sites frequented by scientists were asked to include our invitation and establish links with the ICE2000 web site. Using online forms, potential judges were asked to provide information on their areas of science expertise, previous experience in judging science fairs, and any other relevant qualifications. The criteria for selection were a strong science background and a desire to get involved in secondary science education, and those chosen were found at the Shedd Aquarium in Chicago, MIT, Brookhaven National Lab, and in Italy, Botswana, even Iceland. The majority of the judges were science professors, science graduate students, or research scientists in government or industry. Approximately 25% of the judges were science educators, science education graduate students, or science teachers whose students were not participating in the competition. Some of the judges interacted with the students from home, some from their laboratories; some had to connect after midnight local time while others did their judging early in the morning; and some were logged on for many hours, interacting with the students. All of the judges felt that they had experienced something very different and many stated that the experience was very educational, both for themselves and the students. Of course, not everything worked perfectly and it soon became apparent that while technology did some things very well, other things might be better accomplished in a traditional face-to-face setting.

### **What is a Collaborative Virtual Learning Environment (CVLE)?**

A collaborative virtual learning environment (CVLE) is a shared space available online where learners can interact, communicate, and build knowledge [2]. In other words, a CVLE is a subset of cyberspace where learning takes place.

### **What is a MOO?**

A MOO is a Multi-User Dimension Object Oriented. A MOO consists of two main parts, a MOO server and a database. When a participant connects to a MOO, they can either create a new character or connect to one that already exists. In a MOO, everything is an object. A character is an object, and even rooms and *their exits* are objects [3]. All of the MOOs that exist today are descendants of the original

LambdaMOO written by Pavel Curtis [4]. A webbed MOO allows a user to access the MOO using a web browser. A very good introduction to educational uses of MOOs can be found in the collection of articles edited by Cynthia Haynes and Jan Rune Holmevik [5]. MOOs have been used for a great variety of purposes and at nearly all school levels, from elementary school students who built virtual worlds, to college students and doctoral candidates during their dissertation defenses. In this project, a webbed MOO was chosen for the following reasons:

- 1) It is freeware for educational purposes.
- 2) It functions well over relatively low bandwidth connections and on typical desktop computers, both Mac and Windows.
- 3) It allows multiple modes of communication, both asynchronous and synchronous.
- 4) It allows users to build and construct objects and virtual worlds.
- 5) It allows the use of many types of media, including sound, graphics, VRML, and Shockwave, video and audio conferencing.
- 6) It is relatively easy to install and can function on multiple platforms.
- 7) MOOs have been used to create large communities of people successfully.

This last reason is probably the most important. The ability of users to build in the MOO makes it a very flexible tool. ScienceMOO was structured and utilized in a "divide and conquer" strategy; it was obvious that utter chaos would result if more than 200 students and 64 judges were in one room chatting about their projects. Instead, each project was given its own room and access to the room could be easily controlled using simple MOO objects and commands, such as locking, closing doors, etc. A private room was also provided for the judges. One can connect to ScienceMOO using any Java-enabled Web browser, e.g., Netscape or Microsoft Internet Explorer to connect to the following URL: <http://www.nyu.edu/education/scied/moosnyu.html>. Once someone connects to ScienceMOO, he or she can move through the rooms of ScienceMOO by clicking on links or typing in commands. Users communicate by typing in a manner similar to that used for chat rooms.

## Results

The activity in ScienceMOO varied tremendously during the first year of the project. During off-peak periods, one might find a few students puttering around in their rooms, trying out commands, chatting with other students, or visiting other rooms to check out the competition. A few judges might be found in rooms diligently reading web pages or in the judges' room chatting with their fellow judges. About three weeks before the competition, the level of activity in ScienceMOO increased sharply and during the two weeks of judging, the MOO became a literal hive of activity.

The judging of projects was originally scheduled for the first week of June, but it was extended for an additional week. Feedback was obtained from the students, teachers, and judges using online forms, and this data, together with the project scores, are still being analyzed. The judging process can be illustrated using one of the winning senior projects entitled, "How Do Homogeneous and Heterogeneous Groups Affect Test Taking?" This student's topic was one of very practical concern to both teachers and students: do students work better on problem-solving tasks in groups that are homogeneous or heterogeneous when these groups are based on ability level? The judges who met with this student commented on how valuable and interesting the interaction was, even though at first glance the presentation on the web site definitely needed improvement. For example, a physics professor who judged this project spent more than an hour in discussion with the student. Since the judges were from very different areas of science and not experts in the social sciences, the student was required to give a detailed explanation of the topic of his research and in effect, teach each judge. In return, the judge was able to critique the design of the experiment and give valuable insights to the student. This was an example of an interaction where the judges and the student both gained substantial knowledge. The rigorous questioning and interaction with the judges helped the student arrive at a much more realistic assessment of the results of his experiment. In the case of this student, the online interaction with the judges definitely helped the student improve his critical thinking skills and understand the limitations and strengths of experimental research.

Preliminary results from the online science expo showed that, among other things, the majority of participants had a very positive experience. Both students and judges enjoyed the convenience of being able to connect via the web. The main complaint of the students was that they wished there could have been more judges. Lack

of judges was caused by judges spending far more time interacting online with each group of students than originally anticipated. Another problem that emerged was that the students tended to come online to be judged "en masse" and these times were usually during mid-morning or early afternoon. Many scientists just were not available at these times. As a result, three judges visited most students, but not all.

It quickly became apparent that the structure of ScienceMOO would have to be very adaptable and capable of change at a moment's notice. URL links to student projects changed from moment to moment, schedules changed, and projects were added and dropped. A less flexible tool than a MOO would have failed miserably to react quickly enough when necessary. The key to this success was determined by two important properties of the technology tool chosen:

1. The administrators in charge of the MOO, traditionally called "wizards," were able to change virtually any feature of the MOO almost instantly.
2. The students and judges could make changes themselves in their rooms if they knew the proper MOO commands.

## Conclusions

Technology made many things possible that could never have been accomplished in a face-to-face science fair. In spite of the problems, technology did automate and improve many of the time-consuming tasks needed to organize and carry out a science fair. This enabled the judges to spend more time interacting with the students and evaluating the project web pages. The other great benefit of online science fairs is that it changes national and international science fairs from an elitist event to one that is more egalitarian. An extremely wide variety of students, of varying ability levels, participated in ICE2000. Students from different grade levels and with differing ability, including both English speakers and English as a Second Language (ESL) students, rubbed virtual shoulders with each other; all were able to interact with each other and with scientist judges. An online community that cut across socioeconomic backgrounds, ethnic lines, and grade levels was established. Online judging also allowed scientists whose busy schedules might have precluded time-consuming, face-to-face judging, to take part.

Paradoxically, scaling up the event to involve much larger numbers might enable the most serious problems to be solved. If a large number of international judges from

various time zones can be enlisted, and a team of science graduate students is hired to be on call during peak judging times, the judge availability problem could be solved. The use of technology can allow the benefits of sustained authentic science research to be made available to larger numbers of students. A prescribed, pre-built, and unchangeable collaborative virtual learning environment would fail miserably in accommodating a dynamic online event involving large numbers of individuals.

However, MOOs are only a stepping-stone in the quest for the perfect collaborative virtual learning environment. MOOs are still at a clumsy and awkward stage; they don't always function well. In addition to technical difficulties, they do take some getting used to, and can be very disconcerting for first-time users. MOOs or their analogs, and their successors will need to develop much more user-friendly interfaces that enable higher-bandwidth communication and seamless updating of the database before they become truly useful educational tools. In the meantime, however, they can bring about collaboration and create communities that would not be possible otherwise. The progeny of MOOs could very well be the "constructivist learning environments" that so many educational technology researchers are seeking [6]. ■

## Bio

Brian Murfin completed his Ph.D. in Science Education at Ohio State University. He is presently Assistant Professor of Science Education in the Department of Teaching & Learning, School of Education, New York University. His research interests are in the uses of technology in science education.

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## USING UNDERGRADUATE TEACHING SCHOLARS IN A LABORATORY COURSE FOR NON-SCIENCE MAJORS

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Although laboratory instruction for non-science majors is a major goal of higher education, its implementation is often difficult in practice. Non-science students are often uncomfortable with a laboratory environment and require close supervision for the laboratory instruction to be effective. To address this problem, support from the New York Collaborative for Excellence in Teacher Preparation (NYCETP) was used to recruit and train undergraduate Teaching Scholars to assist in the instructional laboratories of NYU's core science program. The Teaching Scholar was paired with a graduate student laboratory instructor to create a "teaching team." Responses on student evaluations show that the arrangement enhanced student learning in the laboratory because both instructors were present during the laboratory session to provide assistance and answer questions. New initiatives in the project include recruiting students from both science and science education programs, thereby fostering interaction on methods of effective laboratory instruction.

### Introduction

Science instruction for undergraduate students who are not science majors is a challenging goal of higher education [1]. Since 1995, we have embarked on an ambitious project at New York University (NYU) to offer laboratory-based science courses for non-science undergraduates. This has been achieved through the creation of the *Foundations of Scientific Inquiry* (FSI) program, a component of the Morse Academic Plan that constitutes NYU's new core curriculum. A central motivation for designing this new curriculum arose from dissatisfaction with the previous distribution requirement, in which most science courses did not have a laboratory component. The FSI program was created with the conviction that non-science majors could not properly understand the process of scientific investigation without the opportunity to experience it first-hand in a laboratory environment. NYU's commitment to laboratory-based science in the general education curriculum is in accord with national trends in science education reform. The National Science Foundation's influential report on *Shaping the Future* promoted the central goal that students learn science by "direct experience with the methods and processes of inquiry." [2] Similarly, a recent report on undergraduate

Science, Mathematics, Engineering, and Technology (SME&T) education, commissioned by the National Research Council, recommended that science courses include "laboratory rich experiences." [3] A focus on laboratory instruction for all students has been promoted by reports from Project Kaleidoscope [4] and the recent study of education in research universities by the Boyer Commission [5].

The *Foundations* curriculum consists of three sequential courses: Quantitative Reasoning (mathematics), Natural Science I (physical science), and Natural Science II (biological science). These courses are currently offered in three or four different versions each semester, thereby enabling students to select a course that best matches his or her interests. For example, course offerings in Natural Science I include *Einstein's Universe*, *Energy and Environment*, and *Exploration of Light and Color*; whereas, courses in Natural Science II include *Human Genetics*, *Brain and Behavior*, and *Human Origins*. Each of the Natural Science I and II courses is taught in a lecture size of about 120 students, who are then separated into six laboratory sections of approximately 20 students each. Laboratory sessions are taught by trained graduate students who are each responsible for two laboratory sections. These instructional sessions are only 1 hr. 40 min. in duration, which is unusually short for a science laboratory. The FSI program began in the College of Arts and Sciences and has now expanded to include students from the School of Education, the Stern School of Business, and the School of Continuing and Professional Studies. The enrollment of education students in the program was considered essential for improving instruction in mathematics and science for the future generation of teachers. Participation by the business school reflects the belief that future graduates need scientific knowledge and comprehension to become effective leaders in the corporate world. The FSI program currently provides courses for over 1400 students each semester, with a projected increase to 1700 for the 2000-2001 academic year.

Operating with a program of this scope and scale has provided us with experience in developing and implementing effective educational strategies when teaching laboratories in a general education curriculum. One key observation is that non-science undergraduates are often inexperienced and uncomfortable in a laboratory environment, thereby requiring more direct assistance as compared to science students. Consequently, one laboratory instructor often cannot offer the necessary degree of close



attention that is required for non-science majors to gain a significant educational benefit from the laboratory experience. In order to address this problem, we initiated a pilot project to train and utilize undergraduate teaching scholars in the FSI laboratories, which was initiated and funded by the NYCETP collaborative. The goal of the project was to pair the Teaching Scholar with an experienced graduate student to create a “teaching team” that would be more effective at promoting student learning in the laboratory session. The initiative began during the Spring 1999 semester and is being repeated during the Spring 2000 semester. This paper describes the implementation and outcome of the project, together with its impact on curriculum development at NYU.

### **Undergraduate Teaching Scholars - Recruitment and Training**

For the Spring 1999 semester, potential candidates for the Teaching Scholars positions were recruited through upper-level classes in science. All applicants were interviewed and the selection was based on both academic ability and statements of teaching objectives. For their involvement, each Teaching Scholar was paid a small stipend from the NYCETP grant. The first four Teaching Scholars were all science majors (one from physical anthropology, one from neural science, and two from chemistry). In order to focus the initiative, the Teaching Scholars were assigned to the FSI course on *Energy and Environment*, which provides an overview of the science and policy implications of contemporary environmental issues such as global warming, ozone depletion, acid rain, etc. Laboratory projects for this course include: Gases in a Breath; The Properties of Light; Molecular Models; Water Quality Testing; and Photovoltaic Solar Cells. Each Scholar was paired with a graduate student laboratory instructor who served as a collaborator and teaching mentor. We train our graduate laboratory instructors to engage the students by circulating within the laboratory room, offering assistance and asking questions to probe students’ understanding of the experiment. In turn, the graduate student assisted the Teaching Scholar to interact with the undergraduates in the laboratory session. In addition to assisting with two laboratory sections, the Teaching Scholars also attended the weekly course meeting, together with the laboratory instructors, in order to run through the experiment for the following week and discuss how the scientific principles could be taught most effectively. My role was to provide general oversight of the Teaching Scholars, including attending laboratory sessions to observe their teaching in practice.

**Evaluation**

In order to evaluate the effectiveness of the Teaching Scholars, we conducted a survey in the final laboratory session of the semester. Students were asked to give a ranking of 1 – 5 for three numerical questions, which are shown along with the results in Table 1.

**Table 1: Numerical Survey Results for the Teaching Scholars**

Survey Question	Average Score <sup>1</sup>
Did the addition of the Teaching Scholar improve your learning experience in the labs (1 = no improvement, 5 = great improvement)	4.00
Did the Teaching Scholar collaborate effectively with the laboratory instructor (1 = not effective, 5 = very effective)	4.41
Did the Teaching Scholar assist with your understanding of the lecture material (1 = did not assist, 5 = greatly assisted)	3.94

<sup>1</sup> Average scores are given for a total of 136 responses.

In addition to the numerical scores, the survey form asked students to provide written comments on the effectiveness of the Teaching Scholar in the laboratory environment. Most of the comments were positive as illustrated by the sample quotes shown in Table 2.

**Table 2: Quotations from Teaching Scholar Evaluation Forms**

“Two of them floating around asking questions is definitely better than one.” “I would like to take this class again just for the Teaching Scholar.” “He was really helpful in the labs and in review sessions before tests.” “He was a very good Teaching Scholar and made the class better.” “It was a great benefit having him for the labs.” “I thought it was useful and helpful to have someone else in the room...She was always helpful when we had questions.” “Together they were very effective, since there wasn’t only one instructor in the whole class.” “Two teachers were able to assist students better during labs.”
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“It was good to have an extra person around to explain and answer questions.”

“It was helpful to have two instructors.”

“There was more one-on-one help.”

“It did help because there were two people to ask.”

These evaluation results suggest that the Teaching Scholars were effective in meeting the central objective of the initiative, which was to provide enhanced instruction for non-science majors in the laboratory. The student comments often mentioned the beneficial effect of having an additional instructor to answer questions and assist students with the experimental procedures.

### **Revisions of the Project for Spring 2000**

In the Spring 2000 semester, we are again using the Teaching Scholars in the *Energy and Environment* course, but this time we have made significant revisions to the project. The first change is to actively recruit students both from science programs and the science education program in the School of Education. This initiative grew from interactions between the FSI program and the School of Education in the context of the NYCETP collaborative, and was pursued in an effort to stimulate interaction between science majors and science education students. Of the three Teaching Scholars for the Spring 2000 semester, two come from the science education program.

The second change concerns the nature of the laboratory projects. One significant concern about laboratory instruction is that experiments tend to become formulaic, so that students focus only on getting “the right answer.” We have introduced a new approach to laboratory instruction in which students participate in an inquiry-based project. Previous research has shown that a similar lab project approach proved effective in correcting students’ misconceptions in a biology lab course [6]. Each project is designed to extend over five weeks and explores a particular aspect of local water quality; for example, “Can Hudson River Water be Made Safe to Drink?” and “What is the Effect of Acid Rain on Plant Growth?” During the project, students collect their own water samples, design experiments, plot their results using an *Excel* spreadsheet, and generate their own scientific conclusions. The culmination of the investigation is that students create a poster and present their results and conclusions to their Scholar students

in the laboratory group. Although the water quality projects were piloted during the Fall 1999 semester, we encountered major difficulties with their implementation because the undergraduate students require considerable assistance in designing and performing open-ended experiments. We believe that utilization of the Teaching Scholars to aid students in the laboratory during these projects will greatly enhance their effectiveness.

## Conclusions and Future Directions

The NYCETP-sponsored Teaching Scholars initiative has considerably enhanced the quality of instruction in the FSI teaching laboratories at NYU. In addition to the beneficial effects for the undergraduates, the Teaching Scholars themselves have commented on how the experience has improved their skills in scientific communication. To improve the assessment of the project, evaluation is planned to determine the impact of the experience on the Teaching Scholars' chosen career paths. The success of the Teaching Scholar in fall 1999 was used as the basis of a grant to NYU's Curriculum Development Challenge Fund to extend the program throughout the 2000-2001 academic year. In addition, the Teaching Scholar model is currently being explored as a way to involve graduate students from NYU-affiliated medical schools as assistants in the FSI laboratories.

The author would like to thank all of the Teaching Scholars and graduate teaching assistants who participated in the project. Professors Kenneth Goldberg, Neville Kallenbach and Brian Murfin from NYU were also closely involved with the Teaching Scholars initiative at NYU. ■

## Bio

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## **USING EVALUATION TO FOSTER NYCETP GOALS: CASE STUDIES AND INTERCAMPUS COLLABORATION**

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This article describes the use of case studies as part of the formative evaluation conducted for the New York Collaborative for Excellence in Teacher Preparation (NYCETP). While case studies are often conducted for evaluations by outside experts, consultants, or evaluators themselves, we developed a strategy for case studies that used NYCETP faculty to case-study each other. This strategy involved cross-campus collaboration and cross-discipline (Arts & Science and Education) collaboration, and thus actively supported one of the NYCETP goals. The case study strategy also included the development of a faculty (peer) review form for evaluation of documentation of new and revised courses. Procedures for case studies and examples of case study benefits for faculty and evaluators are also described.

### **The NYCETP and Internal Evaluation**

The New York Collaborative for Excellence in Teacher Preparation (NYCETP) is a project with five campuses of the City University of New York (CUNY) and New York University (NYU). The internal formative evaluation is carried out by the Center for Advanced Study in Education (CASE) of the Graduate Center of CUNY. During the first year of the project, CASE focused on typical formative evaluation activities. These included documentation and formative feedback on collaborative workshops and conferences, and ongoing consultation on collaborative goals and implementation of particular activities, such as the workshops. In addition, an evaluator attended the meetings held by the principal investigators, and the internal and external advisory committees. The goal of the Collaborative was to produce “well-qualified teachers of science and mathematics for New York City schools and to increase the number of individuals who enter and successfully complete teacher preparation requirements in science and mathematics.” The Collaborative efforts to meet this main objective can be presented in six clusters of activities: (1) rethinking college instruction — methodology and structures; (2) developing new courses and programs; (3) developing new curriculum materials; (4) providing student support and career development; (5) recruiting promising students into teaching; and, (6) developing exemplary field sites for students.

In late spring, after reviewing collaborative goals and activities, the evaluators decided to attempt to focus the evaluation activities to actively promote very targeted NYCETP goals. The diversity of goals was resulting in a lack of focus for key project goals. These goals were: faculty development (1), and intra- and inter-campus collaboration in developing courses and curriculum materials, (2) and (3) above. We developed plans and procedures for cross-campus case studies of courses being revised and/or developed by NYCETP participants.

A case study strategy was deliberately designed to involve faculty in the same discipline area (i.e., science or mathematics) to talk one-on-one with another faculty member about a specific course. Although many of the conferences and workshops involved faculty presentations about a particular course or curriculum, there was not the detailed analysis of the context of the course, the students, and the curriculum that would be involved in a case study approach. Further, responses to evaluation feedback forms at these workshops and conferences confirmed that these activities provided formal and informal forums to converse about common ideas, issues, experiences, and concerns. However, the activities left faculty expressing a number of needs. These needs included requests for: more information on strategies to change instruction; more feedback and guidance on changing course materials; more in-depth discussions of actual course examples (including student work); and, opportunities to sit in on innovative math and inquiry-based courses, as well as facilitation of inter- and intra-college faculty visits.

All of these evaluation feedback reports supported the decision to have the evaluation activities focus clearly on the goals of faculty development, specific courses, and the cross-campus involvement of faculty in a case study process. Our goals were: (1) to focus on key courses taken by teacher education students — whether in liberal arts and sciences (A & S) or education; (2) to have NYCETP faculty from one campus go to another campus; (3) where possible, to involve in each individual case study an A & S faculty member and an education faculty member; and (4) where possible, to have the faculty member observe an actual class in the course being case studied. These goals have been met to varying degrees in the case studies conducted over the four years of the project, as discussed below.



## The Case Study Process

The most frequent use of case studies in evaluation is illustrated by such projects as the one carried out by Stake and his colleagues [1]. In their project, a group of evaluators very experienced in writing case studies in evaluation visited a series of NSF-funded projects in teacher education and then wrote in-depth descriptions of each project for archival purposes. These descriptive documents are often considered “non-traditional” program evaluation [2], and are also more frequently used now in mixed method evaluations [3]. Case studies are valued for providing sufficient information that readers can form their own interpretations of the “case” being presented. Individual evaluators visit each project or case (or course in NYCETP) and write a case study, much as an individual anthropologist or field-based researcher in sociology would do [4].

In the context of NYCETP, we formalized the case study to some degree in order to assist faculty to focus on aspects of the course that met the NYCETP goals. We drew on earlier work [5] to develop an outline for the case study. The purpose of the outline was to provide guidelines for faculty writing the case studies. The outline included the following categories: context, student-target population, faculty background, physical facilities, curriculum and materials, instructional methods, student outcomes and assessments, faculty roles, cross-discipline and field site collaboration, and course revision plans. Both the year one outline and a revised outline based on faculty feedback are available in ERIC [6].

The intent of the case study process was also to develop baseline reports that provided information about the courses before revision, as well as information on faculty practices and beliefs about teaching at that time. In the first year of the project, the co-principal investigators of NYCETP were asked to identify one or two courses on each campus for detailed documentation. They were also asked to identify faculty on their campuses who already teach courses similar to those identified for study, to carry out the case studies; that is, to write a detailed description following the outline. The case study faculty then visited another campus to observe a class and meet with the course instructor to obtain details about the course curriculum, materials, instructional methods, student outcomes, and assessments. Once the case study was written, it was sent to the evaluators, who reproduced copies and distributed them to the two faculty participants, the NYCETP central office, and one to each campus co-principal investigator for the

campuses involved in an individual case study.

Faculty participants in the case studies were given stipends of \$750 to write a case study and \$250 to be case studied. Faculty members who were teaching the courses were responsible for meeting with the faculty writer, collecting examples of course materials and student work, and clarifying aspects of the course as needed by the writer.

### **The Case Study Outcomes and Products**

Year one case studies were carried out for eight courses and involved ten faculty, three in education and seven in A & S on the six campuses. Three courses were offered in education departments, four in mathematics departments, and one in a science department. Year two case studies were carried out for four courses and involved nine faculty (three in education and six in A & S) on four campuses. Two courses were in science departments, one was in mathematics, and one in education. Year three case studies involved three courses and six faculty (one in education and five in A & S) from five campuses. One course was in each area — education, mathematics, and science. Year four case studies were carried out for five courses, with eight faculty (two education and six A & S) involved. The faculty were from five campuses and a community college. One course was in an education department and four were in departments of mathematics.

Over the four years of the case studies, all of the NYCETP campuses were involved at least once, and a community college was involved in the fourth year. Thirty-three faculty members participated across the four years and twenty courses were documented in the process. These courses were distributed across the areas of education (6), mathematics (10), and science (4). As these numbers show, the sciences were not as well represented as mathematics.

Following the year one's case studies, faculty were interviewed about the case study process. Faculty reported that the outline was useful and the interactions had facilitated collaboration across campuses, as well as understanding of reform-based teaching and learning, in some instances. The in-depth visit on another campus assisted faculty to become clear about facilities that were necessary. One faculty member reported that she was better prepared to provide a request for space and materials than she

had been prior to writing the case study. Others reported changes in thinking about course revisions, such as incorporating more computer graphics and simulations, evaluation of entrance requirements for courses, increasing collaboration among students, and using manipulatives as an integral part of a course, and the need for greater coherence between math and math education courses. One faculty member interviewed reported the difficulties inherent in collaboratively revising courses (i.e., A & S faculty and education faculty).

The case study documents are the primary outcomes of the case study process, and a related, peer review process was recommended and described in year two [7]. Although the peer review process was not carried out, the *NYCETP Guidelines for Self-Study of Course Documents/Curriculum* was used in two ways. The first was in conjunction with faculty workshop/meetings discussing sample course documents and revisions. In this instance, the *Guidelines* provided feedback to faculty. The second was with the course case study documents, and in this respect the *Guidelines* served to provide some indication of the fidelity of the course to national standards and NYCETP goals.

The *Self-Study Guidelines* included check lists and ratings on whether course documents/curriculum met the collaborative student-centered instructional goals, course content goals, course/materials minimum expectations, and evidence of effectiveness of goals in mathematics and/or science, including student attitudes or other outcomes. There were also ratings for CETP programmatic goals (e.g., collaborations, alternative assessments, partnerships, urban context, and dissemination goals). The *Guidelines* were accompanied by a glossary of terms. Ratings of 13 course revision documents were summarized at the end of year three [7]. The ratings provide some indication that these courses were more student centered — that is, there was at least some use of inquiry-based approaches, focus on deeper understanding, and/or an emphasis on problem solving and critical thinking.

In the fifth year of the project, the *Guidelines* have been adapted and modified for review of lesson plans of students in methods courses in elementary mathematics and/or science. This revised rating form is currently being used in a pilot study with a small number of education faculty who are teaching methods courses. Again, the

purpose of these guidelines for reviewing lesson plans are to focus on CETP goals and to provide a method for faculty and students to review their work, in this case for lesson plans.

### **Case Study Benefits: Highlights**

The outcomes above indicate the scope and procedures of the case study process and do not adequately convey the richness, depth, and impact on faculty of some of the case studies. Qualitative outcomes provide another perspective on the benefits of the use of faculty case studies in evaluations. The examples here highlight the benefits of faculty case studies both to the individual faculty and to evaluators, as well as supporting the project goals as cited above.

In the 1996 year one case studies, there were five faculty in mathematics and mathematics education who formed the beginnings of an enthusiastic working group in mathematics that met through the next two years of NYCETP activities. The individual meetings of pairs of faculty to discuss courses and common problems resulted in correspondence between them and sharing of course materials. In 1997, there was a case study of an exemplary collaboration between a mathematics faculty member and a high school teacher. The course, *Sequential [high school] Mathematics from an Advanced Standpoint*, was offered in the Department of Mathematics and Statistics, and was intended for students preparing to be high school mathematics teachers. The mathematics professor collaborated in the course development and was a participant observer for the duration of the course. The course instructor was the high school teacher who was writing an extensive document on the course development, syllabus, sample problems, and student responses as part of the requirements for a masters degree. One of the formative evaluators visited the class in session, facilitated the adaptation of the masters project into a case study, and asked the mathematics professor to write his substantive reflections on the course; the evaluator also wrote an overview to the two documents. The case study process offered flexibility and the resulting documents have also been disseminated outside the NYCETP (NSF National Visiting Committee and Queens College).

In 1998, there were also two exemplary case studies, one in science and one in science/mathematics education. The weekly one-hour recitation for *General Physics*:

*Introductory Course in Mechanics, Heat, and Sound* was case-studied by a physics professor from another campus. The recitation used *Mathematica* for a series of computer-based exercises with a focus on numerical solutions of physics problems. The case study offered the physicist an opportunity to thoughtfully place the use of *Mathematica* for exercises within: considerations of physics as a science; traditional and reform-oriented physics education; and, the goal of creative problem solving by analytical mathematics, potentially supported in the recitation exercises by numerical methods.

The second exemplary case study in 1998 was conducted by a professor in the Department of Mathematics and Computer Science, who visited a class on another campus and met with the education professor who developed the course, *Applications of Microcomputers to Mathematics and Science Instruction*. The course is conducted with hands-on use of major aspects of computer technology, and a syllabus and web links for the class. Assignments included developing web pages, group projects, lesson plans, research paper or grant proposal, and using “tool software,” as well as other instructional software. This was required for undergraduate students in the mathematics/science teaching programs. The course is highly praised by the computer science professor, who planned to disseminate information about the course/web site to education faculty on his own campus. The case study describes an effective integration of technology, instructional theory, and science/mathematics, including links with schools. The case study benefitted the computer science professor, making clear the challenge of NYCETP goals: the course required both extensive knowledge of science and computer tools-applications, as well as continually evaluating new web sites and creating links to them. The course instructor’s major goal was use of technology for enhancing student learning in mathematics or science.

The qualitative outcomes of faculty learning and deepening understanding of the NYCETP and national standards in science and mathematics are clear benefits of using the case study process. These intangible benefits appear to derive from the faculty’s exposure to other teaching examples and the use of case study writing which provide an opportunity to focus and reflect on the teaching and learning processes in classrooms similar to their own.

The major benefits for evaluators are “windows” into faculty course procedures and materials, as well as faculty reflections on courses other than their own. Further, the case studies provide sufficient detail that can be used with the *NYCETP Guidelines for Self-Study of Course Documents/Curriculum*. It is possible to make judgements about the extent to which courses meet NYCETP goals, as was done with the set of individual course documents prepared for the Collaborative. Overall, the use of faculty case studies provides benefits to faculty and evaluators, and supports overall NYCETP goals of collaboration between campuses and education/liberal A & S faculty.

### **Summary and Implications of the Case Studies**

The NYCETP formative evaluation has been innovative in asking university faculty interested in teaching to be involved in conducting case studies. The original evaluation impetus for the case studies was to provide baseline data on courses designated for reform, and then to restudy these courses when revisions were completed. This was an unrealistic expectation. However, the case studies do include several excellent examples of reform courses, although at least two of these course reforms were well underway when the Collaborative began its first year. As mentioned above, the case studies provide sufficient detail for project staff, faculty, and evaluators to assess the fidelity of course reform to national standards and goals.

One of the most positive outcomes of the case studies was the cross-campus interaction among faculty, in depth, about individual courses. From the perspective of formative evaluation, the case study process directly supported the NYCETP goals. The use of NYCETP faculty participants, particularly in the first year, did contribute directly to faculty improvement of their course development efforts. This result, along with somewhat similar work by Muller [8] suggests that evaluators, particularly in the formative stages of projects, can add to project outcomes by developing strategies to directly involve participants (here, faculty) in the ongoing work of evaluation. The extension of the case study outline into the peer review process of course evaluation, and now into ratings of lesson plans, begins to provide a network of evaluation activities that support faculty development and can be transferred to ongoing project activities if project leadership continues.

The implications from the evaluator’s perspective are to make an active use of

evaluation activities to involve program participants in developing and/or refining evaluation “tools” or instruments, as well as using them. Well-structured, these evaluation activities and tools become a way to provide information and feedback for the participant’s own use, as well as for evaluation. ■

## Bios

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# **The Journal of Mathematics and Science:**

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## **PART II: REGULAR JOURNAL FEATURES**

Virginia Mathematics and Science Coalition



# **ATTITUDES IN PHYSICS EDUCATION: AN ALTERNATIVE APPROACH TO TEACHING PHYSICS TO NON-SCIENCE COLLEGE STUDENTS**

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In this article, we present an alternative way of teaching conceptual physics for non-science majors by depicting the role of physics in today's technology. The goal of this approach is to increase in the minds of non-science students the acceptance of physics as a useful component in general education, and as a major tool in comprehending the present-day technological world experienced by students outside the classroom.

## **Introduction**

The complexity of today's technology is built on straightforward physical principles that govern modern materials, scientific processes, and physical devices. Students use this technology daily, but many are unaware of how and why its systems and devices work. Students who are generally aware of the usefulness of materials and devices can be motivated to seek an understanding of the principles underlying their operation by starting the learning process with the products (to which the application of physical principles led), rather than by developing first the quantitative laws (that could eventually suggest such applications).

By using this approach, students who would otherwise have inhibitions regarding the scientific method in describing physical laws will become more receptive and may even develop an interest in understanding in detail, and possibly quantitatively, these physical principles. Furthermore, this approach will expose students to many practical applications of today's technology which are not covered systematically in other introductory physics courses.

## **Perception of Physics By Students**

Science in general is a human activity aimed at discovering the order of things in nature and finding the causes producing this order. Physics, essentially the study of matter, force, energy, and their effect upon one another, plays a central role within the sciences because it is the most inclusive, seeking knowledge fundamental to all branches of science.

Physical principles underlie all natural phenomena and constitute the foremost component of understanding the technology that encompasses the tools, techniques, and procedures of modern life.

Given the importance of physics in understanding the world around us, we might predict that learning physics would have enormous appeal for all people. We would expect that large percentages of high school students would be taking physics, and that this would reflect a broad general interest in physics and thereby lead to an increase of students entering careers having physics as a major component. However, statistics from the Virginia State Department of Education of the number of high school students enrolled in physics in the state of Virginia during the 1992-1993 school year, when compared with those enrolled in chemistry, biology, and earth sciences, contradict our expectations. Given student latitude to choose the one science course required for high school graduation in Virginia, only 7.75% out of 190,553 students taking science chose physics. This figure is down from 8.50% for the 1989-1990 school year. For localities in central Virginia, this percentage for 1992-1993 ranged from a high of 11.7% in Chesterfield County to a low of 2.7% in the city of Petersburg.

The overall low percentage of students taking high school and introductory college physics has been a concern throughout the nation for many years. In 1974, John Bailey [1] wrote:

"Without question, one of the biggest problems in college physics teaching is how to reach and draw in students not majoring in the sciences. The size of the opportunity and problem are attested to by the rash of "non-calculus" physics textbooks which has broken out since 1970. Some of these books have taken the approach of making physics easy. This has meant removing most of the numerical aspects. In many cases, what is left is a discussion about physical phenomena, not physics itself. Crucial formulae whose omission would leave just about nothing to talk about are injected without justification. In my opinion this not only insults the student but fortifies the belief that science is foreign, inhuman, magic, something cooked up by and for geniuses, and the best the student can hope for is to memorize enough of it to pass the course."

The following observations point to the fact that a major component of the failure of

physics to attract a broad audience has to do with the unfavorable perception of physics among non-science majors. Kuhn and Faughn [2] state that the "... common attitude of nonscientists,... which often appears when a student enters a physics class,... is one of fear. It will be too mathematical, or it will be too abstract, or it will be too difficult, and so on. Physics is all of these things." Long [3] summarizes the general perception of physics by non-science majors: "I hate physics; it's got to be the most boring subject in the world!" "I'm terrified of physics! You have to know all that math." "Physics is just memorizing formulas, and then guessing the right one to plug numbers into." "Physics has nothing to do with my major. I don't know why they make me take it."

Armed with knowledge of this perception, educators have tried to improve enrollment in physics courses by rethinking both content and presentation to increase their appeal to students. This has resulted in a rash of conceptual physics texts, with varying amounts of mathematical content. However, progress in improving enrollment has been slow. According to a recent study conducted by a consortium of four institutions (Michigan State, Rutgers, Stanford University, and the University of Wisconsin at Madison), freshmen are less prepared now for college-level courses than a generation ago. Science faculty have observed that, "the very best students are still prepared as well as they used to be, but there is a whole larger group that is not. It is like we've lost the middle group of students." [4] Further evidence of this gap was noted in a presentation in the Chautauqua Faculty Development Program in 1989: "The college introductory physics is in trouble. Texts are getting thicker and students are entering with poorer preparation. Methods of reducing failure rate include stretching out the course or instituting preliminary courses."

### **Science Literacy in the U.S.**

The unfavorable perception of physics and the consequently poor enrollment in physics classes are parts of an alarming problem facing this nation. In 1991, even the top 10% of U.S. students, when compared with comparable populations of students from other countries, ranked near the bottom for 13-year-olds in both math and science, behind students from every other economically developed country except Spain [5]. Only 40% of high school graduates take chemistry and only 19% take physics. This situation has direct implications for college-bound students. The proportion of college students who major in engineering is six times higher in Japan (4%) as in the United States (0.7%), and the engineering doctorate for U.S.-born graduate students is almost a thing of the past. Foreign nationals now receive one-quarter of the natural science degrees awarded in the U.S. Moreover, most of the

advanced American graduates enter fields other than those of their secondary school instruction, thereby aggravating the crisis caused by a shortage of qualified science teachers.

Teachers tend to teach the way they were taught. Therefore, if fundamental changes are to be made in ways of teaching and learning science, intervention must begin with those who teach in the lower grades and continue through high school and college level science educators. The quality of middle and high school science and mathematics instruction is linked partially to the shortage of qualified science teachers. For example, 68% of U.S. high school science teachers teach outside their major field of study, 29% of high schools have no physics teacher, 17% have no chemistry teacher, and 8% have no biology teacher [6]. Large numbers of middle school science and mathematics teachers are inappropriately assigned, teaching courses for which they have not been trained. Only about 20% of physical science teachers are teaching the subject for which they were best qualified. Among physical science teachers (physics and chemistry), only 32% had majors or minors in their subjects and only 16% had a minor in science education.

### **Curriculum Practices in Local Colleges**

As the twenty-first century rapidly approaches, the central goal of science education is to prepare a scientifically literate citizenry. As a nation, we want our students to graduate with an essential level of scientific sophistication in order to successfully accomplish their duties as voting citizens and productive members of the American and global economies. Recent national studies have demonstrated an alarming degree of scientific illiteracy not only among the general population in the United States, but also among students at all levels of education [7, 8]. As Robert Hazen and James Trefil of George Mason University state: "Every university in the country has the same dirty little secret: we are all turning out scientific illiterates, students incapable of understanding many of the important newspaper items published on the day of their graduation." [9, 10] Lynn Arthur Steen relates the scene at a recent Harvard commencement where one graduate after another is asked, "What causes the seasons?" Each answers with complete assurance that, since the earth does not travel in a perfect circle, winter occurs when earth is farther from the sun, and summer when earth is closer. But when asked, "Well, then, why is it summer in the southern hemisphere when it is winter in the north?" the confidence disappears as students realize that they don't know the answer to either question [11].

Part of this dilemma lies with how science is taught to non-science majors in college

and with which courses non-science majors are required to take [12,13]. VCU education professor Richard Rezba has written, "While critics were quick to blame everything from curriculum to societal values for the failure, universities share the responsibility for making the improvements necessary to prepare students to work in, contribute to, and enjoy an increasingly scientific and technological society." [14]

An equally disturbing national problem is the significant under-representation of females and minorities studying and appreciating science, as well as so few members of these groups becoming professional scientists and science educators [15, 16]. To females, science is simply not very "user-friendly" in the classroom [17, 18] or sufficiently attractive as a career choice [19].

Data gathered within the past five years indicate that some of these problems exist at VCU [20]. Bill Stump, a professor of chemistry at VCU, has noted: "I became alarmed during the 1970's about the large number of students who withdrew from or failed our general college chemistry course. Lacking in most of these students is a knowledge or understanding of the important general science laws of physics which are necessary to the understanding of many chemical principles."

### **Advances in Physics Instruction at VCU**

Students view the scientific method with varying degrees of discomfort, helping perpetuate the misconception that physics is unapproachably difficult. Contributing to this is the common practice of devising conceptual physics courses for non-science majors as watered-down versions of their calculus-based counterparts. As an alternative, a conceptual physics course entitled *Wonders of Technology* was developed. It uses the alternative method of beginning with today's technological devices and working towards understanding basic principles. The course departs from traditional courses not only by restructuring the sequence of topics, but also by introducing new features crucial for the comprehension of modern technology and the physicist's role in its development. The rationale for this is that, by starting the learning process with the applications of the physical principles (e.g., microwave ovens, NMR tomography, and photocopiers) rather than with the quantitative laws that suggest the applications, the relevance of physics can be more readily established, enhancing student interest and attention.

*Wonders of Technology* exposes students to a wide range of practical applications of

today's technology, connecting physics with other sciences and academic disciplines. The concept of this course has been used in a workshop entitled, "Reality Based Science Instruction for Middle School Teachers," and funded by SCHEV under the Dwight D. Eisenhower Mathematics and Science Act.

### **Description of *Wonders of Technology***

The traditional physics course for non-science majors generally involves the same sequence of topics covered in a majors physics course, appropriately diluted. Typically, the sequence of topics in a two-semester traditional course are: time and motion, interactions and forces, energy, waves, electrical and magnetic phenomena, atoms, and modern physics. *Wonders of Technology* restructures this sequence and discards the traditional introduction of concepts. Rather, this course begins with real technology and dissects the modes of function and materials used in order to introduce physical concepts. Along the way, the importance of physics is relayed by using examples that are crucial for the comprehension of physics and the roles of mathematics and physical sciences in the development of the products or techniques under discussion. The new format also stresses project/laboratory/hands-on components.

### **Course Content**

Physics courses involving case studies in technology enrich a liberal arts curriculum through motivation for science learning, introduction to the techniques of problem formulation and solving, and bringing together disparate academic disciplines. Consider an example: Magnetic Resonance Imaging is a novel, noninvasive method used to identify cancerous tumors in the brain. It is based on the interaction between a magnetic field and atomic nuclei situated in the brain tissues. This method was developed through knowledge of a physical phenomenon called "nuclear magnetic resonance," and it was applied to live tissues. This was made possible by clearly understanding the chemistry and biology involved in the interaction. Furthermore, analysis of the immense amount of raw data to be processed into useful information was made possible by the use of high speed computer technology. Using numerous case studies that are pertinent to the everyday lives of non-science majors, *Wonders of Technology* introduces topics in the following sequence:

- (1) The concepts of work, energy, and conservation in a philosophical and common sense perspective;
- (2) Materials (relationship between microscopic structure, physical properties, processing



and the environment);

- (3) The structure of matter, basic interactions, atomic structure and its influence on the macroscopic properties of the materials (possession of adequate mechanical properties is essential for the existence and continuity of all forms of life);
- (4) Devices (concepts of forces, work, and energy are developed at the macroscopic level using levers, gears, pulleys, springs, photography, printing, music, electricity, and computers to explain movement, friction, energy, waves, electric forces and currents, and how these are harnessed);
- (5) Processes (influence of processing materials on their resulting micro-structure, macro-structure, and overall properties).

## Methodology

*Wonders of Technology* stresses project/laboratory/hands-on components. We describe here in some detail the major characteristics of the methodology employed in the course: vertical integration design, project centered format, and interdisciplinary content.

- (1) Vertical Integration of Material. Although developed at the freshman, non-science student level, *Wonders of Technology* is designed for easy vertical integration, so it can serve as the basis for redesigning 200-level physics, biology, and chemistry courses for science majors.
- (2) Project/Laboratory Centered Unit Format. Lecture and laboratory components are integrated in a logical sequence and stress the following objectives:
  1. Students should learn something pertinent to their lives;
  2. Students should develop a desire to learn more about the phenomena under study;
  3. Students should reach a conceptual/qualitative understanding of natural phenomena and of their relevance to science, technology, and society.

The three course segments (I, II, and III below) provide for interaction between instructor and students for each topic.

Segment I: Lecture Component The instructor's presentation uses multimedia and is interactive. During this period, the instructor introduces topics from life-related experiences. These topics emphasize the interdisciplinary nature of the phenomena to be examined and the evolutionary nature of the technology, stressing historical, cultural, and philosophical relevance. Topics in this phase are introduced in ways that require problem solving and that raise more questions. Additional information related to a topic (from the same discipline or

a related discipline) is frequently introduced by requiring individual students to conduct hands-on projects and present their results to their classmates.

Segment II: Laboratory or Investigative Activity Small groups of students develop investigative activities (designing an experiment to test a certain hypothesis) or carry out assigned projects (building a radio, for example) that have relevance to the topics developed during Segment I. For the investigative activities, students are presented with physical concepts or issues and required to design an activity that illustrates them [21, 22]. Students first prepare and submit an outline of the project, its goals, and a list of materials necessary to conduct the activity. Projects are reviewed by the instructor and revised as necessary; then, the group is given the requested materials. Following completion of investigative activities, the results are summarized by the students and presented to the class. Both investigative activities and assigned projects are conducted in three stages, each of which could be considered as an end in itself, and are designed in order of increasing complexity, depending on the degree of skill of the group performing them. Upon completion of the first stage, students earn a minimum grade of “C”. Students who satisfactorily complete the next level earn a “B”, and those who complete the third and most advanced level earn a grade of “A.”

Segment III: Enrichment Components A necessary complement to the large lecture and/or the conclusion of the hands-on projects is for students to discuss the topic, its relevance to personal life, technology, and other sciences. For large classes, weekly "breakout" sections of 20-30 students are scheduled for discussion of enrichment topics. This type of “socialization” often involves discussions focused on the interdisciplinary nature of the phenomena under examination. Current events are emphasized by using recent news clippings or articles to explore underlying ethical issues and political themes. Prearranged debates are an especially useful tool to convey the concept that ethical dilemmas related to physics and the sciences often have more than one solution. Students write essays on assigned topics, go on field trips, and use interactive computer programs.

- (3) Interdisciplinary Content Students in *Wonders of Technology* (or similar courses with interdisciplinary approaches) gain a broader understanding of all science, not just one particular field, thereby enhancing their scientific literacy and increasing their retention of science-related knowledge. Furthermore, students learn how to obtain additional information on a scientific subject if required by their occupation or stimulated by personal curiosity at a later date. Making *Wonders of Technology* interdisciplinary requires a combination of elements of physics, biology, chemistry,

geology, and the humanities in a manner that helps students develop the ability to think critically about technical issues so they can use basic scientific principles to make informed decisions throughout life. Approaches used in this course span a wide range of teaching methodologies which include: multimedia presentations (laserdisc, CD-ROM, etc.) in the large lecture (“Segment I” above); objective investigative laboratory exercises (“Segment II”) designed to promote critical thinking, communication skills, and scientific literacy; and “guided” recitations (“Segment III”), in which small groups of students criticize and challenge contemporary scientific and technical issues on both personal and global scales.

Multidisciplinary topics capture student interest. An essential tool in this course is the use of topics of contemporary social or political interest. Once the topic is introduced, it is a simple matter for the instructor to show the physical, biological, and chemical processes beneath the issue. The method continues as the class examines social and ethical processes that affect potential solutions or uses of technology. Some examples include:

(a) Light of Life The topic of photosynthesis is approached by exploring: 1) the cellular structure of a plant leaf, the power plant-like chloroplasts within leaf cells, and the process for exchange of oxygen and carbon dioxide gases; 2) the chemical reactions that occur during the light-independent portion of photosynthesis; and 3) the physical and chemical phenomena that occur during the light-dependent portion of photosynthesis.

(b) Microwaves Microwaves belong to the electromagnetic spectrum, resemble radio waves, and are used in a number of physical and biological applications; including, microwave ovens found in most homes, satellite communication systems, and the small dishes now used by many homeowners for direct TV transmission from satellites.

(c) Magnetic Resonance Imaging MRI is a relatively new physical technology used both as a diagnostic tool for determining tissue damage and as a research tool in cognitive neuroscience. MRI is derived from the field of nuclear magnetic resonance which was first used by physicists and chemists to study detailed chemical features of molecules. MRI technology is based on the fact that atomic nuclei behave like compass needles in the presence of a magnetic field. MRI works because hydrogen

nuclei (protons), making up 80% of animal bodies, can be polarized by being placed in a strong magnetic field generated by an MRI apparatus. The machine then recognizes images produced by the relaxation pulse as the hydrogen nuclei return to their former, randomly-oriented arrangement.

Other topics in brief include:

(d) Depletion of Oil and Natural Resources The flow of energy through ecosystems, geology, recycling, economics, and intergovernmental relations are discussed.

(e) Ozone Depletion Interaction of UV waves and chemical bonding, meteorology, chemistry, global warming, and air pollution are discussed.

(f) Overpopulation Energy consumption and effects on the environment, entropy and global warming, technology, and energy co-generation are discussed.

(g) Electromagnetic Radiation Effects Global communication, as well as physiological, health, and mutagenic effects are discussed.

## Conclusion

The *Wonders of Technology* course and the general science instruction methodology discussed in this paper reflect a fundamental change in the underlying paradigm of science and science instruction. Science was formerly a “frontier” to be explored for the sake of knowing and technology was implemented without personal or corporate responsibility. Knowledge of physics and the other natural sciences, and application of the scientific principles have led to a technological revolution known as the “industrialization of society.” Our perception of the current state of science is that technology and society are so interrelated that it would be difficult if not impossible to treat a single scientific field as autonomous or to pursue scientific inquiry without evaluating the multitude of technical and social ramifications of that study. Based on our experience with this and similar courses, we predict that interdisciplinary course content in all courses (both sciences and humanities) will enhance science literacy, retention of scientific knowledge, and the relationship between science and emerging technology. We contend that the instructional paradigm presented here is, in fact, a very reasonable and socially sensible way to teach science courses to non-science majors.

The *Wonders of Technology* course appears to have significantly affected students' perception of physics. Those attending the first *Wonders of Technology* course commented very favorably (on their anonymous Student Evaluation of Instruction forms) about the lecture methodology employed. Students also expressed great satisfaction with the investigative nature of the laboratory component, related in part to the feeling that they were more in control of their educational experience. We believe that investigative labs require students to be active participants and stakeholders in their education and that the thought processes required to perform the investigative labs allow students to "take home and apply" the material they have learned. Students seem to enjoy and appreciate this. ■

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## STUDENT WORK SECTION

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The following student article is a product of a senior thesis project in mathematics at Bates College. The work was supervised by Prof. Bonnie Shulman.

### PATTERNS IN THE SAND: A MATHEMATICAL EXPLORATION OF CHLADNI PATTERNS

---

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Chladni Patterns are formed when sand settles at the nodes of two dimensional standing waves, excited on a metallic plate which is driven at a resonant frequency. By considering a two-dimensional rectangular membrane with fixed boundary and constant density as an idealized model of the metal plate, a formula for predicting the Chladni Patterns that will form at certain frequencies can be found. In addition to mathematically exploring these mysterious patterns, I have created my own “Chladni Patterns” in the lab.

#### The Genesis

“Seeing M. Chladni's experiments during his stay in Paris excited my interest anew. I began studying...desiring to come to appreciate those difficulties that [were] brought to mind.” -Sophie Germain

Why is it that when a metallic plate, covered with a fine powder, and is vibrated at certain frequencies, beautiful patterns form in the powder? What can be learned from these wonderful “Chladni Patterns”? These questions have intrigued some of the greatest mathematicians, physicists, and even national leaders: Galileo, Laplace, Legendre, Poisson, Gauss, Chladni, Germain, and Napoleon.

The phenomenon of these patterns was first reported by Galileo Galilei almost 400 years ago. Galileo reports in his book, *Dialogues Concerning Two New Sciences*:

“As I was scraping a brass plate with a sharp iron chisel in order to remove some spots from it and was running the chisel rather rapidly over it, I once or twice, during many strikes, heard the plate emit a rather strong and clear whistling sound: on looking at the plate more carefully, I noticed a long row of fine streaks parallel and equidistant from one another. Scraping with the chisel over and over again, I noticed that it was only when the plate emitted this hissing noise that any marks were left upon it; when the scraping was not accompanied by this sibilant note there was not the least trace of such marks.” [1]

Galileo reported this phenomenon, but not a lot was learned about it until the early 1800's when a man named Ernst Chladni became intrigued by it. Ernst Florens Chladni was born in Wittenberg, Saxony in 1756. Raised an only child, Chladni was educated for a career in law. At age nineteen, he took up music and it was through this interest in music that he became fascinated with the patterns which eventually were named for him [2].

Chladni would produce these beautiful patterns by taking differently shaped pieces of metal or glass and sprinkling powder on them. He would then bow along the edge of the metal and the patterns would mysteriously appear.

It was during such an exhibition that Napoleon was first introduced to these patterns and became intrigued. He was “struck by the impact which the discovery of a rigorous theory capable of explaining all the phenomena revealed by these experiments would have on the advancement of physics and analysis.” [3] Because of this interest, Napoleon urged the First Class of the Institute of France to create an incentive for solving the mystery which surrounded these patterns.

The First Class was the section of the Science Academy devoted to mathematics and physics. At the time, there were a number of well-known mathematicians in the First Class: Lagrange, Biot, Laplace, Legendre. The First Class offered a *prix extraordinaire*



of 3000 francs in April 1809 [3] to be awarded to the one who could provide an explanation for Chladni Patterns.

This prize was not won easily or quickly. Because of the rules of the prize, none of the men who comprised the First Class were allowed to submit explanations. The prize was actually reset twice before it was eventually awarded.

In January of 1816, Sophie Germain was awarded the *prix extraordinaire*.

In addition to the work for which Sophie won the *prix extraordinaire*, she made great contributions to the fields of number theory and analysis. Sophie remained secluded from society for her entire life. Maybe this seclusion was the result of the fact that she was a woman in a male-dominated field, or that being an educated woman was out of the ordinary in her day and age. Although she was not shy about her mathematical work, she kept out of the public sector as much as possible.

In 1829, Sophie was stricken with breast cancer. During her two year battle with the disease, she continued to work on mathematics. She succumbed to the fight and died on June 27, 1831 at the age of 55. Unfortunately, Sophie died just a short while before she was to receive an honorary degree from the University of Göttingen, for which Gauss had requested she be considered [4].

## **Vibrating Membrane of Constant Density**

### *Solution to the Wave Equation in 2-D*

What Galileo was witnessing in his laboratory and what Chladni was producing were actually two-dimensional standing waves. The men had stumbled upon the natural frequencies of the plates and by driving them at these frequencies, they were able to produce standing waves. In one dimension, nodes of standing waves are single points, but in two dimensions the nodes are lines. By understanding these nodal lines, we can solve the mystery of Chladni Patterns.

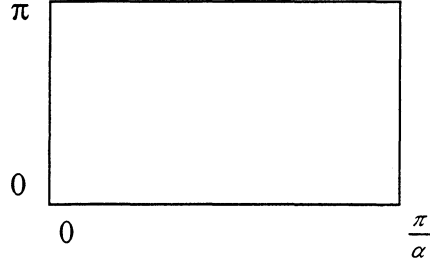


Figure 2.1: Membrane with Dimensions  $\frac{\pi}{\alpha}$  by  $\pi$

Consider a constant density, rectangular membrane. This membrane is completely elastic and has dimensions  $\frac{\pi}{\alpha}$  by  $\pi$ . The shape constant,  $\alpha$ , denotes the ratio of the height of the membrane to the width. We give the membrane an initial displacement, no initial velocity and denote the vertical displacement of the membrane at position  $(x, y)$  at time  $t$  by  $u(x, y, t)$ . The wave equation in two dimensions governs the motion of the membrane if air-resistance is disregarded. (For a dimensional analysis of this equation [in one-dimension] see appendix.)

$$\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2} = \frac{1}{v^2} \frac{\partial^2 u}{\partial t^2} \quad (1)$$

where  $v^2$  is the square of the velocity of the wave. For simplicity, we set  $v^2 = 1$ .

The initial conditions are  $u(x, y, 0) = f(x, y)$  where  $f(x, y)$  is the initial displacement at  $(x, y)$  and  $u_t(x, y, 0) = 0$ .

The boundary conditions are

$$u(0, y, t) = 0 = u\left(\frac{\pi}{\alpha}, y, t\right) \quad \text{and} \quad u(x, 0, t) = 0 = u(x, \pi, t).$$

(The membrane is fixed on all four sides.)

Using the technique of separation of variables, write  $u(x,y,t) = X(x)Y(y)T(t)$ . Substitution into the wave equation gives

$$Y(y)T(t)X''(x) + X(x)T(t)Y''(y) = X(x)T(t)T''(t) \quad (2)$$

or

$$\frac{X''(x)}{X(x)} = \frac{T''(t)}{T(t)} - \frac{Y''(y)}{Y(y)}.$$

Since the left hand side is a function solely of  $x$ , while the right hand side is a function only of  $y$  and  $t$  and since the equation must be true for all  $x$ ,  $y$  and  $t$ , each side must be equal to the same constant.

$$\frac{X''}{X} = -\alpha \quad \text{and} \quad \frac{T''}{T} - \frac{Y''}{Y} = -\alpha.$$

$$u(0, y, t) = 0 = u\left(\frac{\pi}{a}, y, t\right)$$

$$\text{and} \quad u(x, 0, t) = 0 = u(x, \pi, t).$$

By rearranging the equation dealing with  $Y$  and  $T$ , three ordinary differential equations are obtained:

$$\frac{X''}{X} = -\alpha \quad (3)$$

$$\frac{Y''}{Y} = -\beta \quad (4)$$

$$\frac{T''}{T} = -\alpha - \beta \quad (5)$$

where  $\alpha$  and  $\beta$  are constants.

Look at (3). The general solution to this ODE is

$$X(x) = c_1 \sin(\sqrt{\alpha}x) + c_2 \cos(\sqrt{\alpha}x) \quad (6)$$

where  $c_1$  and  $c_2$  are constants.

Using the boundary condition  $u(0, y, t) = X(0)Y(y)T(t) = 0$ , we see that  $X(0) = 0$ . Thus,  $c_2$  must be 0.

Therefore,  $X(x) = c_1 \sin(\sqrt{\alpha}x)$ . It is also known that  $u\left(\frac{\pi}{a}, y, t\right) = X\left(\frac{\pi}{a}\right)Y(y)T(t) = 0$ .

Using this gives

$$X\left(\frac{\pi}{a}\right) = c_1 \sin\left(\sqrt{\alpha} \frac{\pi}{a}\right) = 0.$$

This only happens when

$$\sqrt{\alpha} \frac{\pi}{a} = n\pi \quad \text{where } n \in \mathbb{Z}$$

$$\text{or} \quad \alpha = a^2 n^2 \quad \text{where } n \in \mathbb{Z}.$$

So finally,

$$X(x) = c_1 \sin(anx) \quad \text{where } n \in \mathbb{Z}. \quad (7)$$

Take a look at (4). This is essentially the same equation as (3) and it is not surprising that

$$Y(y) = d_1 \sin(my) \quad \text{where } m \in \mathbb{Z}. \quad (8)$$

and  $d_1$  is a constant. Equation (5) is similar to (3) and (4), except that  $\alpha$  and  $\beta$  have already been determined,  $\alpha = a^2 n^2$  and  $\beta = m^2$ . So the general solution to (5) is

$$T(t) = a_1 \sin(\sqrt{a^2 n^2 + m^2} t) + a_2 \cos(\sqrt{a^2 n^2 + m^2} t)$$

where  $a_1$  and  $a_2$  are constants.

Use the initial condition which dictates there is no initial velocity,  $u_t(x, y, 0) = 0$ , to find that  $a_1 = 0$ . Therefore,

$$T(t) = a_2 \cos(\sqrt{a^2 n^2 + m^2} t). \quad (9)$$

Thus, the general solution for  $u(x, y, t)$  is

$$u(x, y, t) = \sum_{n=1}^{\infty} \sum_{m=1}^{\infty} b_{nm} \sin(anx) \sin(my) \cos(\sqrt{a^2 n^2 + m^2} t). \quad (10)$$

The coefficients,  $b_{mn}$ , can be found by using the initial condition that gives the membrane an initial displacement,  $u(x, y, 0) = f(x, y)$ .

$$u(x, y, 0) = \sum_{n=1}^{\infty} \sum_{m=1}^{\infty} b_{nm} \sin(anx) \sin(my) = f(x, y).$$

This is a 2-dimensional Fourier sine series and, in fact,  $b_{mn}$  can be found by solving for the Fourier Coefficients of this series. So,

$$b_{nm} = \frac{4a}{\pi^2} \int_0^{\frac{\pi}{n}} \int_0^{\frac{\pi}{m}} f(x, y) \sin(anx) \sin(my) dx dy.$$

So the general solution to the two dimensional wave equation when applied to the membrane is

$$u(x, y, t) = \sum_{n=1}^{\infty} \sum_{m=1}^{\infty} b_{nm} \sin( anx ) \sin( my ) \cos\left( \sqrt{a^2 n^2 + m^2} t \right) \quad (11)$$

where

$$b_{nm} = \frac{4a}{\pi^2} \int_0^{\frac{\pi}{n}} \int_0^{\frac{\pi}{m}} f(x, y) \sin( anx ) \sin( my ) dx dy.$$

It can be assumed that  $f(x, y)$  is continuous since this fits with the physical situation.

### *Nodal Lines*

Now that an equation for the vertical displacement of a constant density membrane has been derived, what does this say about the mysterious Chladni Patterns? Well, Chladni Patterns are formed when powder or sand settles at the nodal lines of a plate which is being driven at one of its natural (or resonant) frequencies. Using this equation for the vertical displacement, let's try to identify these natural frequencies and predict the nodal lines.

In general, an infinite sum of periodic functions is not periodic. To have a periodic function, and therefore find a common period, the frequencies of each term must be rational multiples of one another.

In this case, for an arbitrary initial displacement,  $f(x, y)$ , the general solution will not be a periodic function with respect to  $t$ . The angular frequency for the  $n, m^{th}$  term is  $\sqrt{a^2 n^2 + m^2}$ , which is in general irrational. As  $n$  and  $m$  step through integer values, the frequencies are not rational multiples of one another. Therefore, the overall function is not periodic and it does not even make sense to talk about a common period. Only periodic functions admit of resonance (the whistling sound noticed by Galileo in conjunction with the patterns) and combinations with a common period are necessary to form standing waves.

Certain initial displacements do lead to solutions which are periodic functions. For example, consider an initial displacement  $f(x,y) = \sin(ax)\sin(y)$ . With this displacement,

$$b_{nm} = 4 \begin{cases} \frac{1}{4}, & \text{if } n = m = 1. \\ 0, & \text{if } n \neq m \neq 1 \end{cases}.$$

Therefore,  $b_{11} = 1$  and  $b_{nm} = 0$  for all  $n \neq m \neq 1$ . This produces a very nice expression for the vertical displacement of the membrane.

$$u(x, y, t) = \sin(ax) \sin(y) \cos(\sqrt{a^2 + 1}t) \quad (12)$$

This function is periodic in  $t$  with angular frequency  $\omega_{11} = (\sqrt{a^2 + 1})$ .

Now  $u(x,y,t)$  is a function which is periodic in  $t$  and governs the vertical displacement of the membrane. But what about nodal lines?

Nodes occur where the membrane is not moving, i.e, where the amplitude of the vertical displacement is zero for all time  $t$ . From (12), it can be seen that the amplitude is  $\sin(ax)\sin(y)$ . (Note that  $n = m = 1$ .) Where is this zero? The amplitude is zero when  $\sin(ax)=0$  or  $\sin(y) = 0$ . This only happens when  $ax = c\pi$  or  $y = d\pi$ . So

$$x = \frac{c\pi}{a} \quad \text{or} \quad y = d\pi \quad \text{where} \quad c, d \in \mathbb{Z}.$$

Since the membrane has dimensions  $\frac{\pi}{a}$  by  $\pi$ , consider  $c$  and  $d$  to be only 1 or 0.

Therefore, the nodal lines are  $x = 0$ ,  $x = \frac{\pi}{a}$ ,  $y = 0$  and  $y = \pi$  and the membrane will look like a one by one grid.

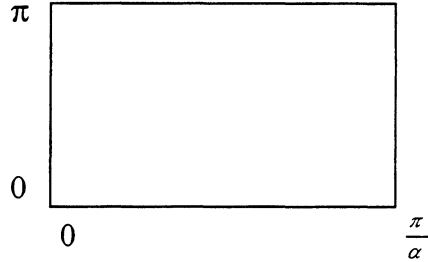


Figure 2.2: A 1 x 1 grid.

Since the boundary is fixed, it is not surprising that there is no movement along the edge.

Now consider a solution in which  $n = 2$  and  $m = 1$ . This gives a vertical displacement of  $u(x, y, t) = \sin(2ax) \sin(y) \cos(\sqrt{4a^2 + 1}t)$ . This is a periodic function with angular frequency  $\omega_{21} = (\sqrt{4a^2 + 1})$ .

Here the amplitude is zero when  $x = \frac{c\pi}{2a}$  or  $y = d\pi$  for  $c, d \in \mathbb{Z}$ .

In this case, consider  $c = 0, 1, 2$  and  $d = 0, 1$  because of the physical features of the membrane. The nodal lines on this membrane form a two by one grid, as in Figure 2.3.

For one final example, look at the case where  $n = 4$  and  $m = 5$ . The displacement is  $u(x, y, t) = \sin(4ax) \sin(5y) \cos(\sqrt{16a^2 + 25}t)$ . The nodal lines appear at

$x = \frac{c\pi}{4a}$  and  $y = \frac{d\pi}{5}$ . Here  $c$  is an integer from 0 to 4 and  $d$  is an integer from 0 to 5. The nodal lines form a four by five grid as in Figure 2.4.



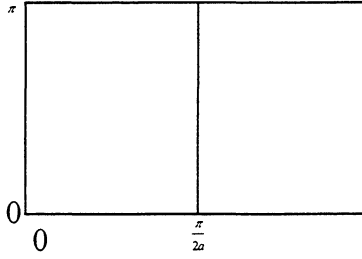


Figure 2.3: A 2 x 1 grid

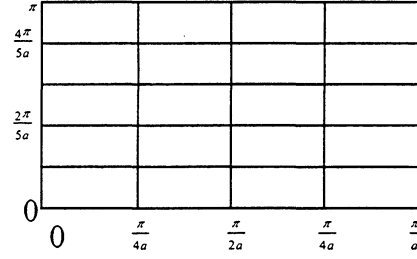


Figure 2.4: A 4 x 5 grid

In general, it is then easy to see that, if the vertical displacement of the membrane is  $u(x, y, t) = \sin( anx ) \sin( my ) \cos( \sqrt{a^2 n^2 + m^2} t )$ , then the amplitude is zero when

$$x = \frac{c\pi}{an} \quad \text{and} \quad y = \frac{d\pi}{m} \quad \text{where} \quad c, d \in \mathbb{Z}$$

with  $0 \leq c \leq n$  and  $0 \leq d \leq m$ .

Using this information, it is clear that the displacement pattern (the pattern formed by the nodal lines) is in general an  $n$  by  $m$  grid.

Now that a way to predict mathematically what the nodal lines will look like has been determined, what do all of these assumptions mean in the real world? What is being examined is the case where the membrane is given an initial displacement. This particular initial displacement is chosen so that it will produce a standing wave. From this initial displacement and the standing wave which it produces, the frequency at which the membrane will vibrate is determined.

For example, in the case where the vertical displacement is  $u(x, y, t) = \sin(ax) \sin(y) \cos( \sqrt{a^2 + 1} t )$ , the nodal lines can be predicted.

In an ideal world, this standing wave would never dissipate and the membrane would continue to vibrate until someone stopped it. The frequency of vibration is determined by the time component of  $u(x, y, t)$ . Here the angular frequency is  $\sqrt{a^2 + 1}$ . This means that, disregarding air-resistance, if a membrane is given an initial

displacement of  $f(x,y) = \sin(ax) \sin(y)$ , it will continuously vibrate at an angular frequency of  $\sqrt{a^2 + 1}$  and produce a standing wave and nodal lines.

In general, if the membrane is given an initial displacement which produces a standing wave of the form

$$u(x, y, t) = \sin(ax) \sin(my) \cos(\sqrt{a^2 n^2 + m^2} t),$$

the membrane will vibrate at an angular frequency of  $\sqrt{a^2 n^2 + m^2}$ . The frequencies that you get by cycling through integer values of  $m$  and  $n$  are called the natural frequencies.

If the membrane is covered in a fine powder or sand, and then given an initial displacement which produces vibrations at one of these natural frequencies, the powder will settle into the nodal lines and patterns, of which Chladni was so fond. The displacement patterns which are depicted in Chladni patterns are called the natural modes of vibration of the membrane. Three of these modes are shown in Figures 2.2, 2.3, 2.4.

These natural modes of vibration are what Galileo noticed over 400 years ago. By scraping a metal plate with a metal chisel, he was able to vibrate the plate at one of its resonant frequencies, completely by chance. In his case, instead of sand, it was the metal filings that had been generated by the scraping, that fell into the nodal lines and formed the patterns.

### Producing Chladni Patterns

In addition to working with the mathematics presented above, I also produced my own “Chladni Patterns” in the lab. (For methods, please contact me.) The physical set-up had several differences from the mathematical model. The patterns produced were on a free edge plate. The most obvious difference between this set-up and the mathematical model is that the boundary conditions are different. Another difference is that the idealized model assumes a membrane which by definition has no depth, stiffness, or volume. In the actual set-up, the plate has stiffness and an appreciable depth. The free boundary changes the problem significantly. Rayleigh describes the problem of

calculating the modes of vibration for a plate with free boundary as “extremely difficult.”[5] Rayleigh did find though, that the  $(0,m)$  mode is just like the fixed boundary case. The nodal lines are parallel to the  $y$ -axis. Likewise, the  $(n,0)$  mode has nodal lines running parallel to the  $x$ -axis.

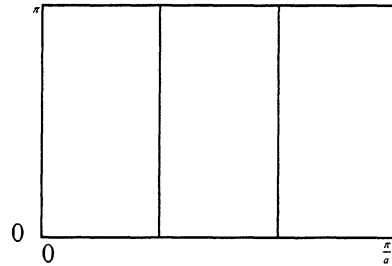
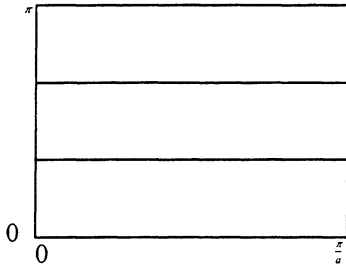


Figure 3.1:  $(0, m)$  Mode of Vibration      Figure 3.2:  $(n, 0)$  Mode of Vibration

The difference from the fixed boundary case comes when the modes are combined to get the  $(n, m)$  mode of vibration. When this is done, the lines tend to bend toward each other and are no longer independent of one another (as in the fixed boundary membrane) (5).

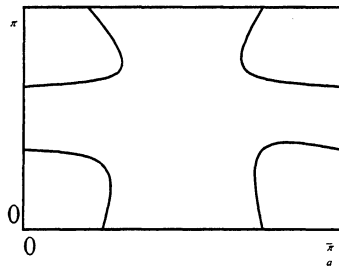


Figure 3.3:  $(n, m)$  Mode of Vibration

These shapes are evident in the patterns produced in the lab. (See following pictures.)

Another difference between the work done in the lab and the problem solved mathematically is that in the real world, there is air-resistance. Because of that, a plate or

membrane can be given an initial condition, but it can not be expected that the plate will vibrate forever. In the ideal world of mathematics, this is exactly what is claimed. If a membrane is given a certain initial condition, it will vibrate at a natural frequency and produce a standing wave which will never dissipate. To deal with air-resistance in the lab, the plate can be *driven* at a natural frequency. When the driving force is cut off, the sound which is produced by the vibration of the plate can actually be heard. This sound does dissipate because of air-resistance and other damping forces, but it does ring for a few seconds. This sound is the same sound Galileo heard over 400 years ago when he was scraping his plate.

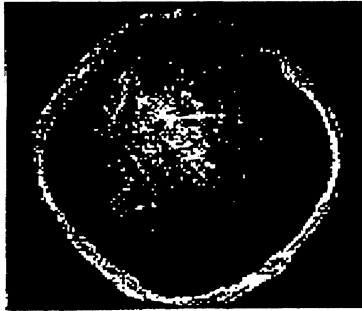


Figure 3.4: Frequency 408.1 Hz

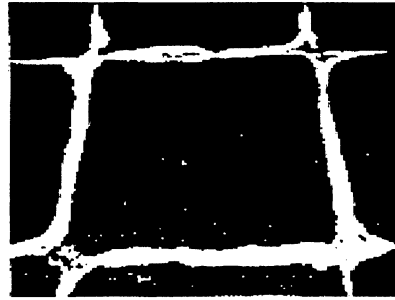


Figure 3.5: Frequency 1057.0 Hz

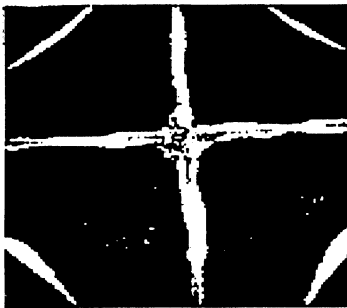


Figure 3.6: Frequency 1281.0 Hz

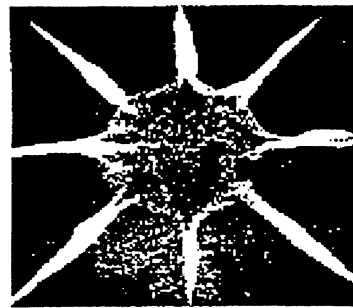


Figure 3.7: Frequency 1147.7 Hz

### A Dimensional Analysis of Wave Equation

In order to verify quickly that the wave equation in one dimension makes sense, let's perform a dimensional analysis.

The variables in the wave equation and their units are as follows:

$$[u(x, y, t)] = \text{length} = l$$

$$[x] = \text{length} = l$$

$$[t] = \text{time} = t$$

$$\{v^2\} = \left[ \frac{\text{tension}}{\text{density}} \right] = \frac{\text{force}}{\text{density}} = \frac{\text{mass} * \frac{\text{length}}{\text{time}^2}}{\frac{\text{mass}}{\text{length}}} = \frac{l^2}{t^2}.$$

Let's look at the units on the left hand side of the wave equation:

$$\left[ \frac{\partial^2 u}{\partial x^2} \right] = \left[ \frac{\partial}{\partial x} \frac{\partial u}{\partial x} \right] = \left[ \frac{\partial}{\partial x} \right] \left[ \frac{\partial u}{\partial x} \right] = \frac{1}{l} * \frac{l}{l} = \frac{1}{l}.$$

Now let's examine the units on the right hand side of the wave equation and hope that they come out to be the same as those on the left hand side:

$$\left[ \frac{1}{v^2} \frac{\partial^2 u}{\partial x^2} \right] = \left[ \frac{1}{v^2} \frac{\partial}{\partial t} \frac{\partial u}{\partial t} \right] = \left[ \frac{1}{v^2} \right] \left[ \frac{\partial}{\partial t} \right] \left[ \frac{\partial u}{\partial t} \right] = \frac{t^2}{l^2} * \frac{1}{t} * \frac{l}{t} = \frac{1}{l}.$$

The units on each side of the wave equation match, so the wave equation makes sense. ■

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## EDUCATIONAL RESEARCH ABSTRACTS

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*Editors' Note:* As noted in previous issues of the *Journal of Mathematics and Science: Collaborative Explorations*, the purpose of this Educational Research Abstract section is to present current published research on issues relevant to math and science teaching at both the K-12 and college levels. Because educational research articles are published in so many different academic journals, it is a rare public school teacher or college professor who reads all the recent published reports on a particular instructional technique or curricular advancement. Indeed, the uniqueness of various pedagogical strategies has been tacitly acknowledged by the creation of individual journals dedicated to teaching in a specific discipline. Yet many of the insights gained in teaching certain physics concepts, biological principles, or computer science algorithms can have generalizability and value for those teaching in other fields or with different types of students.

In this review, the focus is on "background knowledge." Abstracts are presented according to a question examined in the published articles. Hopefully, such a format will trigger your reflections about the influence of students' entering mathematical and scientific conceptions (and misconceptions,) as well as generate ideas about your own teaching situation. The abstracts presented here are not intended to be exhaustive, but rather a representative sampling of recent journal articles. Please feel free to identify other useful research articles on a particular theme or to suggest future teaching themes to be examined. You may send your comments and ideas via email to gmbass@wm.edu or by regular mail to The College of William and Mary, P. O. Box 8795, Williamsburg, VA 23185-8795.

### **Students' Background Knowledge in Mathematics and Science Learning**

"Why is our sky blue?" How would you explain the color of the sky to a middle-aged painter, a beginning elementary schoolteacher, a teenage musician, or a five-year-old neighbor? The kind of conversation you might have with a colleague in the physics department about "Rayleigh scattering" is likely to be very different from your discussion with any of these other four individuals about sky color.

What scientific concepts do you need to understand in order to answer why our sky is blue? Spectrum? Wavelength? Frequency? Hue? Gas molecules? Dust particles? What does your painter, teacher, musician, or preschooler need to know to understand

your explanation? What do you need to know about their current understanding to help you decide how to “teach” them the scientific answer? How can you help them think about related but more complicated questions, such as: “What does the sky look like on our moon?” “What color could the sky be on other planets?” [For a short presentation on how the atmosphere makes different colors and suggested learner activities, check out the Newton Apple Teacher Guide at <http://www.ktca.org/newtons/9/sky.html>.]

One of the fundamental, learner-centered principles about teaching and learning is that one’s existing knowledge serves as the foundation of all future learning (Alexander & Murphy, 1998, in *How students learn: Reforming schools through learner-centered education* edited by Lambert & McCombs.) This principle contends that new information is filtered through that “old” knowledge, connected to a network of “old” associations, and organized into “old” ways of representing that knowledge. Without first considering a learner’s background knowledge about a topic, a teacher is unlikely to provide the best explanation or experiences to help the learner develop a more complete understanding of the concept.

In science and math, students often enter the classroom with incomplete and faulty conceptions about the very topics they are expected to learn. If students believe green plants get their food from outside sources just as animals do, or that a baseball hit into the outfield must have both an upward and forward force acting on it after it leaves the bat, those students not only have to learn “new” scientific ideas, they have to unlearn “old” common sense ones. Howard Gardner in *The Unschooled Mind* put it this way, “...young adults trained in science continue to exhibit the very same misconceptions and misunderstandings that one encounters in primary school children - the same children whose intuitive facility in language or music or navigating a bicycle produces such awe.”(p.4) Teachers who do not verify their students’ existing knowledge before planning and implementing instruction, risk the same failure as giving identical explanations about blue sky color to a college educated teacher and a five-year-old.

So what must a teacher discover about a student to help that student learn? A wise old teacher was once asked, “What do you need to know before you teach someone?” The teacher paused, smirked inscrutably, and replied, “More than they



know!” Certainly we believe that is true, but a more informed teacher might add “... and more about what they already know!”

The following articles describe specific research studies in which initial student understanding (and misconceptions) are important components. Findings from these recent research studies can indeed inform college professors and K-12 teachers on the best teaching practices for helping their students better understand important mathematical and scientific ideas.

- **How do students’ prior learning affect their study of beginning algebra?**

Algebra is easy, right? Students just need to know that alphabet letters can stand for numbers and that these letters can have operation signs attached to them. Add 3 to  $x$  and get  $x + 3$ . Subtract 12 from  $y$  and get  $y - 12$ . Multiply  $z$  by seven and get  $7z$ . Of course the student better not think that  $z$  signifies addition as in  $7\frac{1}{2}$  or place value as in 78! In research with over 2,000 Australian students aged 11 to 15, Stacey and MacGregor discovered that students’ interpretation of algebraic symbolism is strongly influenced by their previous experiences. They describe many sources of student misunderstanding that can interfere with their interpretation of beginning algebra. Students may get confused because they have learned to use letters with other meanings, such as abbreviated words or units of measure. Students can indeed confuse the arithmetic operations in composite symbols such as  $7\frac{1}{2}$ , 78, and VIII. Students may think of the equals sign as “makes” or “gives” and use it to link parts of a calculation. Students can confuse natural language rules for interpreting temporal sequence with the special algebraic “order of operations.” Remember that students arrive in their first algebra course with substantial prior experiences of symbol systems that are not all helpful in comprehending algebraic symbolism. To improve students’ algebra achievement, Stacey and MacGregor urge algebra teachers to recognize the many possible sources of student misunderstanding and explicitly point them out in their own teaching.

K. Stacey and M. MacGregor, "Ideas about Symbolism That Students Bring to Algebra," *The Mathematics Teacher*, **90**(2) (1997) 110-113.

- **How does elementary school children's informal mathematical knowledge about fraction concepts, especially their symbolic representations for fractions, influence their learning?**

Just when young children finally understand the symbolic meaning of whole numbers, teachers introduce them to fractions! Many researchers have predicted that these students' prior knowledge of symbol systems may lead them to overgeneralize or construct inappropriate meanings when presented with fractions. Nancy Mack conducted an intense investigation of four third-graders and three fourth-graders to document how their informal knowledge affected their learning about fractions. She provided six one-to-one, 30 minute instructional sessions for each child during a three week period, and one follow-up session 14 weeks later. Using a combination of clinical interviewing and cooperative problem solving instruction, she posed problems, asked questions, and encouraged the students to think aloud as they solved problems. After each individual session, Mack planned the next lesson based on the student's informal knowledge and misconceptions about fraction symbols and algorithmic procedures. Mack discovered that four students would give one answer to a fraction problem when presented verbally in the context of a real-world situation, and a different answer to a corresponding problem given symbolically. Even after instruction, five students still would interpret the symbol  $a/b$  by saying the numerator was the number of wholes and the denominator was the number of parts in each whole. Mack concluded that her sample of students overgeneralized their knowledge of whole numbers to fractions early in the instruction, and overgeneralized their knowledge of fractions to whole numbers at the end of their instruction. She admits this kind of confusion may be unavoidable as elementary students expand their symbolic concepts for fractions. However, she requests that elementary teachers take the time and effort to acknowledge this potential confusion and create instruction to help students make this necessary transition to a more appropriate symbolic representation of fractions.

N. K. Mack, "Confounding Whole-Number and Fraction Concepts When Building On Informal Knowledge," *Journal for Research in Mathematics Education*, **26**(5) (1995) 422-441.

- **How do chemistry students' understanding of "chemical bond" reflect an *alternative conceptual framework* ?**

Given the extensive research literature about the wide range of learners' alternative conceptions about scientific concepts, especially in physics, Keith Taber explores how generalizable this idea is for chemistry. Using 15 pre-university students, he conducted in-depth interviews, recorded student discussions, administered a concept repertory test, and analyzed students' work samples. He discovered that students typically used the octet rule as an explanatory principle for identifying chemical reactions and chemical bonding. The students' octet rule framework included notions that were incorrect, but also perceptions that represented a more limited understanding of chemical bonding. Taber gives numerous examples of how this partial understanding influences students to hold alternative conceptions of chemical bonding. He believes recognizing this will allow a teacher to understand why a student "sees bond type as a dichotomy; believes in ionic molecules; expects bond fission to always be homolytic; considers 'proper bonds' and 'just forces' to be otologically distinct rather than just different in magnitude; and limits the number of possible successive ionizations to the number of valence shell electrons." (p. 606) Acknowledging these kinds of student interpretations permits teachers to identify appropriate demonstrations and counter-examples to challenge the adequacy of their students' alternative thinking.

K. Taber, "An Alternative Conceptual Framework from Chemistry Education," *International Journal of Science Education*, 20(5) (1998) 597-608.

- **How do chemistry majors conceptualize chemical equilibrium and fundamental concepts of thermodynamics?**

Thomas and Schwenz interviewed 16 volunteer chemistry majors to probe their understanding of equilibrium and fundamental thermodynamics concepts. They discovered that students in an advanced undergraduate class for chemistry majors still showed difficulties with key concepts and topics. For example: 88% of the students did not apply the fundamental equation of the first law of thermodynamics to determine how the first law applies to the presented chemical reaction; 94% did not mention the standard change in entropy and enthalpy as factors that determine the values of equilibrium constants; and, 100% of the students failed to mention the value of  $\Delta G$  is the change in Gibbs energy for the reaction as written when the reaction occurs under conditions of

constant composition of the reaction mixture. Thomas and Schwenz charge teachers to determine the conceptions even of their advanced students and use a variety of active learning/teaching strategies to create the disequilibrium necessary for students to move toward the experts' conceptions.

P. Thomas and R. Schwenz, "College Physical Chemistry Students' Conceptions of Equilibrium and Fundamental Thermodynamics," *Journal of Research in Science Teaching*, **35**(10) (1998) 1151-1160.

- **How can a teacher assess students' misconceptions using both interviews and multiple-choice tests?**

Most studies of students' misconceptions about science and mathematics have used individual interviews, a time consuming procedure that is usually limited to a relatively few participants. Philip Sadler examined whether a paper and pencil instrument that could be group-administered would provide equally valuable insights into students' alternative conceptions. He constructed a multiple-choice test with 47 items that gave a single correct answer, and several alternative conceptions previously identified through student interviews. For example, "The main reason for its being hotter in summer than in winter is (a) the earth's distance from the sun changes; (b) the sun is higher in the sky; (c) the distance between the northern hemisphere and the sun changes; (d) ocean currents carry warm water north; (e) an increase occurs in 'greenhouse' gases." This instrument was administered to 1,250 eighth through twelfth grade students at the beginning and end of their introductory astronomy courses. Sadler also asked their teachers to predict students' scores on these items at the end of the course. He discovered that his test did indeed diagnose students' conceptions of astronomy and allowed better measurement of students' stagelike progression in conceptual understanding. He also discovered that students of moderate ability would frequently revert to alternative conceptions before returning to the scientifically correct concept. Furthermore, Sadler concluded that the time needed for lasting conceptual change is much longer than teachers believe. (Students in this study only showed one-eighth of the gain in understanding that teachers predicted for their courses!) Based on this research, it appears crucial that test constructors and curriculum developers identify students' alternative conceptions as necessary stepping stones to genuine scientific understanding.

P. Sadler, "Psychometric Models of Student Conceptions in Science: Reconciling Qualitative Studies and Distractor-Driven Assessment Instruments," *Journal of Research in Science Teaching*, **35**(3) (1998) 265-296.

- **What is the relationship between freshmen's prior knowledge, study orientation, and logical thinking ability on their overall performance in a nonmajor's chemistry course?**

Any science professor who teaches nonmajors will almost certainly have experienced a wide range in student performance on course exams and assignments. Previous research on this issue has pointed to students' prior subject matter knowledge, their achievement in science, and their formal reasoning ability as influential factors. BouJaoude and Giuliano chose to examine those factors, and students' approaches to studying, in a large, two-semester, freshman, nonmajor chemistry course (199 students: 114 women and 85 men). In the first semester, they asked the students to complete an Approaches to Studying Inventory (adapted from Entwistle and Ramsden's original instrument), a Test of Logical Thinking (developed by Tobin and Capie), and a demographic questionnaire. Students' grades from their initial hour-long exam in the first-semester and from their second-semester final examination were also obtained. BouJaoude and Giuliano found that prior knowledge was the best predictor of course achievement; that is, students' first-semester, hour-long exam scores were the best predictor of their second-semester final exam performance (accounting for about 25% of the variance). Student scores on the measure of formal reasoning ability, the TOLT, were also statistically significant predictors of students' final exam scores, but this variable only accounted for less than 6% of the variance. They discovered that knowing students' study orientation did allow a significant, but small, improvement in predicting their final exam scores. It appears that students who study using active questioning strategies, relating ideas to other parts of the topic, and expressing intrinsic motivation do better than students who emphasize memorization, rely on teachers to define learning, and prefer extrinsic motivation. However, BouJaoude and Giuliano caution that a balanced study strategy where students memorize key facts, concepts, and generalizations in order to create meaningful relationships among them may indeed be the best approach. They recommend all teachers of nonmajor science students pay close attention to those students' prior knowledge, logical thinking abilities, and methods of studying in order to provide the best instruction to address deficiencies in their entering capabilities.

S. B. BouJaoude and F. J. Giuliano, "Relationships Between Achievement and Selective Variables in a Chemistry Course for Nonmajors," *School Science and Mathematics*, **94**(6) (1994) 296-302.

- **How does reform teaching influence elementary students' learning about fractions?**

"Six people will share three brownies. How much will each person get if each gets a fair share?" An elementary school teacher who values constructivist reform might engage students with this problem in a lesson that builds on their current understanding, that requires them to solve the problem, and that allows the teacher to monitor and expand the mathematics that emerges from the students' efforts. Another teacher who values a procedural approach to problem solving might introduce this fair-share problem by drawing three rectangles on the chalkboard, partitioning each rectangle into two parts, and calling each part "one-half." This teacher would likely expand this approach to other shapes and other number of parts in order to help the students conceptualize the problem in terms of fractions. A third teacher who values student discovery might introduce the problem by providing students with manipulative materials to explore possible solutions in small groups. After discussion with tablemates, the teacher asks students to share their solution and celebrates student work by displaying it on the class bulletin boards. Will students learn fractions equally well in each of these three instructional situations?

Saxe, Gearhart, and Seltzer investigated this question by observing 19, upper elementary teachers and their classrooms, representing both traditional teachers who taught fractions using school-approved textbooks, and reform teachers who taught fractions using constructivist oriented units (*Seeing Fractions* and *My Travels with Gulliver*). Teachers were observed and videotaped during whole-class discussions when teaching fractions. Using the observational field notes and videotapes, the investigators rated teachers on the alignment of their classroom practices with reform principles; specifically, the teachers' level of integrated assessment and their level of conceptual issues integrated with problem-solving procedures. Students were pre-tested to categorize their knowledge of fractions as "with rudimentary understanding" (313 students) or "without rudimentary understanding" (168 students). Students' achievement was measured with a post-test containing both typical textbook fraction problems and more open-ended, non-routine problems associated with reform-oriented curricula. Saxe,

Gearhart, and Seltzer found that, for children with a rudimentary understanding of fractions, alignment of practice with reform principles was a strong predictor of student achievement on the problem solving items. For children without a rudimentary understanding of fractions, alignment with reform practices only predicted student learning when the instructional alignment was above average. No evidence was found that student performance on computational post-test items was influenced by increasing alignment of classroom practices with reform principles.

Saxe, Gearhart, and Seltzer conclude that the learning of fractions involves a complex interaction of students' prior understandings, teachers' classroom practices, and their assessment of students' problem solving and computational abilities.

G. B. Saxe, M. Gearhart, and M. Seltzer, "Relations Between Classroom Practices and Student Learning in the Domain of Fractions," *Cognition and Instruction*, **17**(1) (1999) 1-24.

- **What is the relationship between pre-service teachers' alternative conceptions of science and their science teaching efficacy?**

If elementary education teachers also hold misconceptions and alternative conceptions of science, how prepared will they be to teach their own students? Can these alternative conceptions be identified during their initial teacher preparation so faculty can provide the necessary instruction to remedy this situation? Schoon and Boone surveyed 619 pre-service elementary education teachers in science methods classes at ten U.S. universities. They administered an instrument that identified twelve alternative conceptions of science (constructed by the investigators) and an instrument that measured science teaching efficacy (modeled on Enochs and Rigg's instrument). While there was no overall significant relationship between the number of alternative conceptions held and a pre-service teacher's science teaching self-efficacy, they did discover an interesting pattern. Pre-service teachers who held the following alternative conceptions also showed low self-efficacy scores: "planets can be seen only through telescopes; dinosaurs lived at the same time as cavemen; rusty iron weighs less than the iron that it came from; electricity is used up in appliances; and north is toward the top of a map of Antarctica." They interpret this finding as evidence that pre-service teachers who maintain these

conceptions face a “critical barrier” to a full scientific understanding that would cause them to struggle in science courses, and feel less able to teach science to others.

Schoon and Boone recommend that specially designed, science content courses utilize active teaching methods that relate concepts, avoid excessive lecturing and memorizing, build on students’ previous experiences, and focus on overcoming students’ alternative conceptions.

K. Schoon and W. Boone, "Self-Efficacy and Alternative Conceptions of Science of Pre-service Elementary Teachers," *Science Education*, **82**(5) (1998) 553-568.

- **Where can I get further information on how to teach math and science more effectively?**

A good first step can be found free and easily accessible on the Web (<http://stills.nap.edu/readingroom/books/str/>) in the Science Teaching Reconsidered Handbook. Here, you will find eight chapters produced by the Committee on Undergraduate Science Education for the National Academy Press. Chapter 4 focuses on misconceptions as a barrier to understanding science. Specifically, it addresses the role of misconceptions in the learning process, describes common science misconceptions, and provides methods to identify and break them down. Only when teachers identify their students' misconceptions, provide a forum for students to confront them, and help those students reconstruct and internalize their knowledge based on scientific models, will true conceptual change be accomplished. Without such deliberate teacher efforts, students are unlikely to surrender their previously held beliefs rooted in the power of everyday experience. ■



## **A I M S & S C O P E**

Articles are solicited that address aspects of the preparation of prospective teachers of mathematics and science in grades K-8. The Journal is a forum which focuses on the exchange of ideas, primarily among college and university faculty from mathematics, science, and education, while incorporating perspectives of elementary and secondary school teachers. The Journal is anonymously refereed, and appears twice a year.

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- research on student learning
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- For article submission, send three copies of the manuscript.
- The body of the paper should be preceded by an abstract, maximum 200 words.
- References to published literature should be quoted in the text in the following manner: [1], and grouped together at the end of the paper in numerical order.
- Submission of a manuscript implies that the paper has not been published and is not being considered for publication elsewhere.
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